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THESIS

EVALUATION AND COMPARISON OF FREEDOM CLASS LCS AND OTHER FRIGATES/CORVETTES AGAINST SMALL BOAT, FPB AND SUBMARINE THREATS IN CONFINED WATERS

by

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June 2009

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This thesis compares the performance of the Freedom Class Littoral Combat Ship (LCS) with five similar international frigates and corvettes in a littoral combat environment. The alternative ships are: Formidable class frigate, Singapore Navy; MILGEM (Milli Gemi) class corvette, Turkish Navy; Steregushchiy class frigate, Russian Navy; Sigma class corvette, Indonesian Navy; and Visby class corvette, Swedish Navy. The study is conducted within a fictitious scenario in the Strait of Hormuz, countering Iran's naval capabilities. Hughes's Salvo Equations Model is used to evaluate a variable number of friendly combatants versus a fixed opposing force. The results identify the number of ships required to dominate the threat in the scenario.

Based on the comprehensive results, including changes by adding hardkill and introducing countermeasure effectiveness, an optimum design suggestion is made. In the end, optimum design is a relative subject because the issues of sustainment and cost play a significant role in the decision. LCS is shown to be the most combat-effective performer, but its cost detracts from its operational advantages. MILGEM is a medium size ship with high performance and lower cost, making her the most cost-effective candidate. Visby has the lowest cost and because of its stealth can be combat-effective as others, but it is not nearly as sustainable. Thus, the decision depends on the weight placed on these several factors.

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TABLE OF CONTENTS

LIST OF FIGURES

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LIST OF TABLES

LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS

AAW	Anti-Air Warfare
ASCM	Anti-Ship Cruise Missile
ASUW	Anti-Surface Warfare
ASW	Anti-Submarine Warfare
C2	Command and Control
CIWS	Close-in Weapon System
CSG	Carrier Strike Group
ECM	Electronic Countermeasure
EMCON	Emission Control
ESG	Expeditionary Strike Group
ESM	Electronic Support Measure
FC	Fire Control
FER	Fractional Exchange Ratio
FP	Force Protection
FPB	Fast Patrol Boat
FRIFOR	Friendly Force
HVU	High Value Unit
IR	Infrared
IRGN	Iranian Republican Guard-Navy
ISR	Intelligence Surveillance Reconnaissance
JFS	Jane’s Fighting Ships
LCS	Littoral Combat Ship
MANA	Map Aware Non-Uniform Automata
MCM	Mine Countermeasures
MILGEM	Milli Gemi (National Ship)
MOE	Measure of Effectiveness
MPA	Maritime Patrol Aircraft
MW	Mine Warfare
OPDEF	Operational Defect
OPFOR	Opposing Force
PDMS	Point Defense Missile System
PGFG	Missile Fast Patrol Boat
PTF	Torpedo Boat
PTG	Missile Boat
RAM	Rolling Airframe Missile
RCS	Radar Cross Section
SA	Situational Awareness
SAG	Surface Action Group
SAM	Surface-to-Air Missile
SLOC	Sea Lanes of Communication
SSC	Coastal Submarine
SSK	Conventional Submarine
SSM	Surface-to-Surface Missile

TF	Task Force
TG	Task Group
UAV	Unmanned Aerial Vehicle
VLS	Vertical Launcher System
WHP	Weapon Hit Probability
WLR	Weapon Launch Reliability

EXECUTIVE SUMMARY

This thesis provides an evaluation and comparison of the Freedom Class Littoral Combat Ship (LCS) and five other similar international frigates and corvettes in a littoral combat environment. The alternative ships are: Formidable class frigate, Singapore Navy; MILGEM (Milli Gemi) class corvette, Turkish Navy; Steregushchiy class frigate, Russian Navy; Sigma class corvette, Indonesian Navy; and Visby class corvette, Swedish Navy. The evaluation is conducted within a fictitious scenario in Strait of Hormuz, countering Iran’s naval capabilities to close the Strait. Iran’s recent acquisition of indigenously built and imported naval capability is a credible threat to freedom of navigation in the region.

The objective is to analyze littoral warship alternatives in a scenario that involves a Friendly Force (FRIFOR) Squadron against Fast Patrol Boat (FPB), small boat, and submarine threats. The main goal is to compare the effectiveness of the LCS Squadron to that of the squadrons of five other FRIFOR candidate designs. Opposing Force (OPFOR) are Iranian Kilo class submarines, Yono class midget submarines, Kaman and Thondor Class FPBs and numerous classes of small, but fast, missile and torpedo boats.

To evaluate the FRIFOR squadron against the OPFOR in terms of weapons exchange, the research methodology uses Hughes’s Salvo Equations Model. For each FRIFOR candidate, seven types of encounters against OPFOR are modeled, resulting in 42 unique encounters. The Salvo Equations

Model produces the Fractional Exchange Ratio (FER). This model computes the number of FRIFOR ships to achieve FER "parity" of equal fractional losses. The results also indicate the number of required ships to achieve "dominance" over the OPFOR in each encounter.

After initial base case encounters are investigated, a hardkill capability boost provided to Sigma and Visby is considered. Another case introduces countermeasure effectiveness to the Salvo Equations to estimate its effect on each outcome. Quantifying countermeasure effectiveness is not an easy task. The approach employed in this study is to answer the question of how much countermeasure effectiveness is enough.

A unique application of the Salvo Equations is the surface ship versus submarine encounter, which has not been heavily investigated in recent years. This study provides a crude first approximation to the encounter and produces important insights. Another aspect of the model is that helicopters are heavily used in the scenario due to the nature of each encounter. This is especially true for LCS because helicopters are its sole offensive weapons option.

The results are enhanced with a sensitivity analysis for better understanding. The findings of this thesis suggest that 7-10 LCS are required to overcome the multi-axis threat in the scenario. Using a completely different analytical approach, a recent thesis suggests the result of 6-10 LCS for a similar threat scenario, lending credence to the findings of both studies. In the conclusion, the number of required ships for each FRIFOR candidate in each encounter is aggregated to make recommendations about

preferences among the candidates. The issue of cost and sustainability are included to evaluate one design against another.

Based on the comprehensive results, including the changes of adding hardkill and introducing countermeasure effectiveness, an optimum design suggestion is made. In the end, optimum design is a relative subject because the issues of sustainment and cost play a significant role in the decision. LCS is shown to be the most combat-effective performer, but its cost detracts from its operational advantages. MILGEM is a medium size ship with high performance and lower cost, making her the most cost-effective candidate. Visby, on the other hand, has the lowest cost and because of its stealth can be as effective as others, but it is not nearly as sustainable. Thus, the results are relative and a decision depends on the weight placed on these several factors. This thesis may directly benefit decision makers who plan future LCS squadron operations in support of Carrier Strike Groups or Expeditionary Strike Groups, as well as protection of the Sea Lanes of Communication in littoral waters.

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I. INTRODUCTION

A. BACKGROUND AND OVERVIEW

Since the fall of the Soviet Union, the world has changed tremendously for the naval warriors. High seas engagement of the enemy has faded in importance. New warfare types, asymmetric and hybrid warfare, have emerged, posing a serious threat to large combatant navies, such as the U.S. Navy. To adapt, countries are taking important steps to focus on littoral warfare and to battle the new threats. In light of these advancements, the U.S. Navy's initiative to build a capable but cost effective ship, in terms of budget, weapons and manpower, has given birth to first Littoral Combat Ships (LCS), LCS-1 USS Freedom, which began sea trials on 28 July 2008, and LCS-2 USS Independence, which is due in 2009.

LCS marked a milestone in U.S. naval ship building history, which has been recently influenced by the building of Israeli Eilat Class corvette, Swedish Visby Class corvette and the Norwegian Skjold Class patrol craft. This shift toward a focus on building littoral type ships is due to the ever-increasing requirements of operations jeopardized by conventional and asymmetric threats in near shore and confined waters. These waters include, but are not limited to, straits, choke points, and sea bodies full of islands and bays. These can harbor and hide surface-to-surface missile (SSM) carrying Fast Patrol Boats (FPBs), small but fast and possibly ship-disabling anti-surface weapon-carrying boats, and conventional and midget submarines. USS Freedom is designed to combat such

adversaries in these environments supporting a Carrier Strike Group (CSG) or Expeditionary Strike Group (ESG) (RAND Study, 2007; CRS Report, 2008). As recommended by recent theses, deploying LCS with the necessary mission packages within a 2-3 LCS Surface Action Group (SAG) or a 6-10 LCS squadron, depending on mission complexity, is required to effectively cover Anti-Submarine Warfare (ASW), Anti-Surface Warfare (ASUW) and Mine Warfare (MW) missions (Abbott, 2008; Milliken, 2009).

With her multiple helicopter and Unmanned Aerial Vehicle (UAV) capabilities, depending on the mission package embarked, Freedom Class LCS is a capable fighter in littorals. Other navies around the world, however, are also adapting to the coastal mission. New German Type 125 class frigates will be capable of staying in littorals up to two years without returning to home base. Singapore’s new Formidable class frigate and the new Indonesian Sigma class corvette are typical examples of a capable vessel combating against piracy in the Strait of Malacca. A Turkish MILGEM corvette, built with indigenous efforts, was launched in 27 September 2008 and is designed to provide security for the Sea Lanes of Communication (SLOC) in the Aegean Sea.

Russia has built her version of LCS, the Steregushchiy Class frigate. The purpose is to create a force of capable but smaller size ships, even though they are under the protection of other larger warships. Perhaps the most shocking design is the Swedish Visby class corvette, which introduces a new design for littorals. These represent only a few navies introducing new capabilities in the littoral. This thesis explores which one is the most suitable for a

given scenario. More specifically: How well does LCS perform compared to some other designs within the following representative scenario?

B. FICTITIOUS SCENARIO

In October 2008, Iran inaugurated her newest naval base at Jask on the Gulf of Oman, 45 NM east of the southern entrance of the Strait of Hormuz (Jane’s Intelligence Digest, 2008). It is assessed that the new base enhances Iran’s capability to close or block the Strait of Hormuz, threatening 40% of the world’s crude oil trade (Fish, 2008). In November 2008, the Iranian Navy Chief, Rear-Admiral Habibollah Sayyari, publicly confirmed (during the commissioning ceremony of Iran’s newest indigenous midget submarine and two FPBs) Iran's threat to close the Strait of Hormuz in the event of hostilities with Israel or any other power (Fish, 2008).

Iran has long been threatening to shut down the Strait regardless of her projected economic losses due to such an act. In the wake of Israeli media speeches that are revealing potential Israeli air strikes on Iranian Nuclear facilities, as well as increased U.S. and multi-national exercises and operations that have targeted Iranian Navy ships and aircraft in the Persian Gulf, Iran responds to the sanctions imposed on her by halting traffic in the Strait of Hormuz (Scott, 2008). Iran openly states that no traffic is to go through the Strait, East or West bound, and that she will target all tanker and merchant vessels attempting to navigate the Strait. This also applies to any naval vessel trying to encounter Iranian Navy ships enforcing this operation.

Iranian Navy and Republican Guard naval forces, known as IRGN, are already capable of threatening Strait transit shipping with the naval assets located in the heart of the Strait of Hormuz. The bases include the Main Headquarters and the 1st Naval District of the Iranian Navy, Bandar Abbas, as well as numerous islands and designated mainland naval bases (Jane’s World Navies, 2009). Iranian naval assets include, but are not limited to, conventional diesel submarines with possible SSM upgrades, midget submarines, semi-submersible torpedo boats, conventional missile-carrying FPBs, and fast small boats carrying short range missiles and/or lightweight (324 mm) torpedoes (Fish, 2008; Gelfland, 2008; Jane’s Fighting Ships, 2009; Jane’s Sentinel Security Assessment, 2009).

Although existing, to focus the fictitious scenario analysis to maritime exchanges, numerous truck-mounted mobile SSM land sites, mine threat, and the Iranian Air Force are not considered. The Iranian Air Force threat and shore-based SSM threat from fixed or mobile sites have been eliminated via tactical and CSG Air Wing strikes. In an attempt to acquire freedom of navigation, one or two Iranian Kilo class submarines have been moved out of the Strait to Bandar Beheshti in the Indian Ocean. An MCM group, in support of CSG or ESG operations, has already cleared all the international waters from the mine threat inside the Strait of Hormuz. The Iranian Navy’s large vessels, such as frigates and corvettes, are obsolete and the operational ones were destroyed along with naval air assets in previous encounters inside the Persian Gulf. (These include Alvand class frigates, Bayandor class corvettes, Parvin class patrol boats, P-3 MPAs, Sea King

and AB 204/212 helicopters.) Therefore, for model simplification, only smaller, faster, newer and missile or torpedo-carrying Iranian naval assets are taken into consideration.

The scenario begins with increased tensions in the Persian Gulf and Iran deciding to challenge shipping in the Strait of Hormuz. Currently, an LCS SAG is operating in the vicinity of the Strait in support of a CSG or ESG that might be in the Persian Gulf or in the Gulf of Oman. Due to the heavy tanker traffic through the Strait, an escort or Force Protection (FP) mission is needed to provide security to High Value Units (HVUs) and to protect oil tankers transiting the Strait. In the context of this mission, the LCS SAG is reinforced with more ships and this squadron of Friendly Forces (FRIFOR) is located in the Strait of Hormuz. The purpose is to encounter and neutralize the Opposing Forces (OPFOR) that will be approaching from (1) mainland Iran (the major naval base Bandar Abbas) and from (2) the islands in and around the Strait. The primary threats are FPBs, small boats, and submarines.

C. THESIS OBJECTIVE

This thesis’ goal is to analyze a scenario that involves a FRIFOR Squadron against FPB, small boat and submarine threats. The primary objective is to compare the effectiveness of the LCS Squadron to that of squadrons of five alternate FRIFOR designs. The study primarily focuses on answering the following research questions.

D. RESEARCH QUESTIONS

- How does a LCS squadron perform compared to other selected frigate and corvette designs?
- In this scenario, how many ships should compose a FRIFOR squadron tasked with fighting an Iranian OPFOR of small combatants and submarines taking advantage of islands and bays?
- What is the effect of OPFOR submarines on FRIFOR performance?
- Are additional offensive and/or defensive weapons capabilities needed for the FRIFOR candidate designs?
- What is countermeasure effectiveness in this littoral scenario?
- Given that UAVs and/or helicopters are already being employed in an ASUW role, how does the lack of SSMs effect LCS's ASUW role against an OPFOR of small combatants?
- How well will an LCS squadron perform in a scenario that involves OPFOR SSM swarm tactics when operating away from the SAM umbrella of a CSG or ESG?
- Are the following attributes of LCS advantages or disadvantages in comparison to the other designs?
    - AAW Capability: rapid-fire medium caliber gun, Point Defense Missile System (PDMS), but no SAM.
    - ASUW Capability: helicopters' missile load, but no SSM.
    - ASW Capability: helicopters' torpedo load, but no ship-launched torpedo.
    - Size, weight and low signatures compared to smaller designs.

- How well does LCS compare with alternative designs? What may be an improved design for LCS and an optimum design for FRIFOR?
- Are there cost-effective design improvements?

E. SCOPE OF THESIS

This thesis addresses capabilities and vulnerabilities of smaller combatants in a dangerous littoral environment. An analytical model is used to formulate the scenario. The model is described in detail and it is followed by the combatants in the scenario. The Analysis and Results chapter details the breakdown of the Battle of Strait of Hormuz. The results and recommendations provide important insights for littoral warfighters as well as a basis for other scenarios that may be investigated using this model.

F. RESEARCH METHODOLOGY

Salvo Equations, developed by CAPT Wayne Hughes, USN (Ret.), are used to compare a weapons exchange of the LCS squadron and the Iranian OPFOR (Hughes, 1995). A model using Hughes' Embellished Salvo Equations is implemented and the results are analyzed. The OPFOR is heterogeneous and the homogenized attributes that factor in the formulas have been validated by CAPT Hughes during discussions. This research has been realized with the inspiration and insights gained from previous works on "An Analysis of Small Navy Tactics Using a Modified Hughes' Salvo Model" by Tiah (2007) and "Littoral Combat Vessels: Analysis and Comparison of Designs" by Christiansen (2008).

G. SIGNIFIANCE OF RESEARCH

This study directly benefits decision makers who plan future LCS SAG/Squadron operations in support of an ESG or CSG as well as FP support to commercial shipping. Primarily, the strengths and weaknesses of LCS against an OPFOR of small, diverse, and capable combatants are displayed in the results of the model. Possible improvements to the LCS are explored by evaluating alternative ship designs within the same scenario. Depending on the scenario and the OPFOR attributes, the model can be altered. Therefore, it is possible to extend this scenario to other parts of the world and associated potential threats.

II. HUGHES' SALVO MODEL

A. INTRODUCTION

This chapter provides detailed information on the model used to formulize the fictitious scenario. Salvo Equations have been developed by CAPT Wayne Hughes, USN (Ret.). Basic Salvo Equations deal with the representation of a missile salvo exchange between warships using SSMs and SAMs (Hughes, 1995). Building on the basic Salvo Equations, an Embellished Salvo Model is used to compare the FRIFOR and the OPFOR. More specifically, the model is designed to represent a weapon exchange and defense encounter between homogenous forces (Hughes, 1995; Hughes, 2000).

In this thesis, the OPFOR is heterogeneous and the resulting homogenized attributes that factor in the formulas were validated by CAPT Hughes during discussions. The scenario, which involves submarine versus surface ship engagement, provides important insights and this encounter has not previously been modeled with the Salvo Equations. Also introduced in the Embellished Salvo Equations are the Anti-Ship Cruise Missile (ASCM) "leakers" (Hughes, 2000). The detailed information on the participants involved in the model, the process in choosing their attributes, as well as the analysis and results, are displayed in later chapters.

B. EMBELLISHED SALVO EQUATIONS

The embellished force-on-force equations for combat work, achieved by a single weapon salvo fired by a homogenous or homogenized force at any time step, are the following:

$$\Delta B = \frac{(\alpha' A - b_3' B) b_4}{b_1} \tag{1}$$

where,

A = number of ships in force A

B = number of ships in force B

ΔB = number of ships in force B out of action from A’s salvo

b_4 = Seduction Countermeasure Effectiveness

b_1 = number of hits by A’s missiles needed to put one B out of action

$$\alpha' = \sigma_A \tau_A \rho_B \alpha \tag{2}$$

where,

α' = fighting power in hits of an attacking A modified for scouting and training deficiencies and the effect of defender B’s distraction countermeasure effectiveness

σ_A = Targeting/Scouting Effectiveness of A

τ_A = Training Effectiveness of A

ρ_B = Distraction Countermeasure Effectiveness of side B

α = number of well-aimed weapons fired by each A ship

$$b_3' = \delta_B \tau_B b_3 \tag{3}$$

where,

b_3' = hits denied to A by defender counterfire of B, degraded for defender alertness and training deficiencies

δ_B = Defensive Readiness/Alertness of B

b_3 = number of well-aimed weapons destroyed by each B ship

$$\Delta A = \frac{(\beta' B - a_3' A) a_4}{a_1} \tag{4}$$

where,

$$\beta' = \sigma_B \tau_B \rho_A \beta \tag{5}$$

$$a_3' = \delta_A \tau_A a_3 \tag{6}$$

The corresponding terms and terminology hold for equations (4), (5), and (6), i.e., replace A with B, α with β, and vice versa.

C. DEFINITIONS OF MODEL PARAMETERS AND ASSUMPTIONS

1. Striking/Offensive Power (α, β)

Striking/Offensive power is the number of well-aimed weapons fired by each ship in a single salvo. Basic Salvo Equations are designed for missile exchange. This thesis, however, requires that the offensive weapons represented in the Embellished Salvo Equations be short- and long-range SSMs and torpedoes. For each encounter and weapons exchange, it is assumed that both sides' offensive weapons are within each others' effective firing range. The number of well-aimed weapons is calculated using the number of ready-to-fire weapons on board, the Weapon Launch Reliability (WLR), and the Weapon Hit Probability (WHP). This, therefore, usually results in a non-integer number.

Striking Power = Number of Weapons * WHP * WLR (7)

The number of weapons is considered the number of ready to fire weapons, i.e., 8 Harpoon long-range SSM canisters on deck or the number of torpedo tubes on ships and submarines. This does not include any possible reserves. WLR is the probability that the fired weapon will leave its launcher successfully. WHP is the probability that the fired weapon will acquire a successful hit at its target, where the target’s defense is not taken into account.

For both forces and all ship and weapon types, the WLR is assumed 0.9. The WHP assumptions for the weapon types are as follows:

Weapon Type	**WHP**
Torpedoes	0.9
Short Range SSMs	0.8
Long Range SSMs	0.7

Table 1. Offensive Weapon Hit Probabilities.

2. Defensive Power (a_3, b_3)

Defensive power is the number of well-aimed weapons destroyed by each ship. Basic Salvo Equations factor in the SAMs. In this thesis, however, defensive power is investigated in depth. This is due to the types (infrared (IR), active or semi-active radar homing) or lack of SAMs, number of Fire Control (FC) channels, as well as ASW, defense against torpedoes. The defensive power of each ship is different against each type of weapon. The parameter in the formula can be a non-integer number.

3. Staying Power (a_1, b_1)

Staying power is the number of hits by opponent's missiles needed to put a ship out of action. In other words, this is the number of hits that could be absorbed before the Combat Power is reduced to zero. Combat Power is defined as striking power minus the target's defensive power. A ship put out of action does not necessarily mean it is sunk; rather, it means it is either a neutralized threat or a firepower kill. The hits required to put a ship out of action linearly diminish her fighting strength. For this scenario, staying power is dependent on the type of weapon (torpedo or missile) that hits the ship. To restate: the staying power of each ship is different against each type of weapon and the parameter can be non-integer.

4. Targeting/Scouting Effectiveness (σ_A, σ_B)

Targeting/Scouting effectiveness is the degradation of striking power measured in hits per salvo. This degradation is due to imperfect detection or tracking of enemy targets. It could be described as the level of efficiency regarding the collection of enemy target information for a successful attack. The parameter takes a value between zero and one, one being 100% effective. A modern frigate with effective radars and organic air asset for scouting should have one for targeting effectiveness. This could, however degrade due to the target's nature, e.g., small and hiding behind an island.

5. Defensive Readiness/Alertness (δ_A, δ_B)

Defensive readiness/alertness is the extent to which a target ship fails to take defensive actions up to her

designed combat potential. This may be due to unreadiness or inattention caused by Emission Control (EMCON) or condition of readiness. The parameter takes a value between zero and one, one being 100% readiness/alertness. A good example of low alertness is when the Israeli Eilat Class Corvette, INS Hanit, was not 100% ready or alert due to operational and intelligence relaxations at the time Hezbollah attacked with a truck-mounted C-802 during the Israel-Lebanon conflict in 2006.

6. Training Effectiveness (τ_A, τ_B)

Training effectiveness is the degree to which a firing or targeting ship does not reach her designed combat potential due to inadequate training, organization or motivation. The parameter takes a value between zero and one, one being 100% effective. This number could portray the level of professionalism of the crew, level of wartime training, spare part and equipment technology constraints, etc. It could be assumed that the Iranian Navy has a lower level of training effectiveness. If not so due to professionalism, this is certainly due to some obsolete ships and equipment and lack of spare parts.

7. Seduction Countermeasure Effectiveness (a_4, b_4)

Seduction countermeasure effectiveness is defined as the level of effectiveness that causes incoming weapons to miss. Thus, it is applied to incoming good shots. When an incoming weapon is homing or locked on to a ship, the seduction phenomenon diverts the weapon away from the ship. This is accomplished by using softkill, a decoy or chaff, as well as other features of the ship, such as low

observability. Seduction chaff/decoy is assuredly the biggest contributor to this parameter. This creates a non-existing target for the weapon to home in on, i.e., a decoy.

Seduction softkill is a major complementary element to conventional hardkill defense, i.e., SAMs. Other contributors may include the stealth level, acoustic fingerprint, IR signature of the ship design, and on. To further enhance this phenomenon, the stealth level, namely the Radar Cross Section (RCS) is accounted for. The smaller the RCS, the better the chance to deny enemy targeting or scouting. Further, if this is combined with a seduction softkill, smaller RCS enhances the effectiveness of that softkill, urging the locked weapon to change course to the non-existing target, which is a fake radar echo. This parameter also takes a value between zero and one. This time, however, one represents the worst case. This is due to the nature of the formulas. For example, a level of 0.85 would mean 15% of the incoming weapons would miss the ship due to seduction countermeasure effectiveness.

8. Distraction Countermeasure Effectiveness (ρ_A, ρ_B)

Distraction countermeasure effectiveness is the level of effectiveness that causes enemy shots to miss before counterfire, which is the defensive power. The purpose of distraction is similar to the seduction phenomenon. The timing, however, is different. Distraction happens preferably before the enemy fires its weapons and prior to the weapon homing on the ship. Certain softkill methods create distraction. The attributes of the ship, however, also play a significant role.

Distraction chaff or creating a fake radar echo, used during enemy’s scouting/targeting phase or even after its missile is fired, will cause the enemy to target or the incoming missile to lock onto the fake radar echo. The ship design features mentioned in seduction countermeasure effectiveness contribute even more to distraction countermeasure. For example, having a smaller RCS in situations where the enemy is far away, will tremendously minimize or eliminate the enemy’s scouting/targeting effort. The enemy may not be able to see the ship on radar or, if a contact is present, it may be confused or “distracted” about which contact to fire at due to insignificant radar echo.

D. INTRODUCTION OF LEAKERS

To better represent real scenarios, the introduction of leakers into the embellished Salvo Equations was deemed necessary. The concept of leakers can be summarized as: no matter how effectively a ship’s crew trains and fights and regardless of the superiority of her personnel, sensors, and weapons, there is an amount of considered leakage from the incoming enemy weapons that cannot be taken out by any means (Hughes, 2000). A case in point is an AEGIS cruiser or destroyer, which has excellent coverage of air space with the 3D SPY radar, is armed with numerous SM-2 SAMs, and has the maximum capability to reduce the leakers from an incoming swarm of cruise missiles, but still cannot assuredly eliminate all incoming missiles all the time.

Note that even if one side has superiority over another with 0 ships lost, there still may be some loss due to leakers. In the embellished Salvo Equations, leakers are

calculated using the following formula and added to the number of ships remaining after a salvo exchange. Leakage rate is the percentage of the incoming weapons that survive defensive counterfire. The resulting value, therefore, is usually a non-integer number:

The number of ships lost to leakers by side A is added to ΔA:

$$\text{Number of Ships Lost to Leakers} = \frac{B * \beta * \text{ Leakage Rate}}{a_1} \quad (8)$$

Leakage rate for each weapon type is as follows:

Weapon Type	**Leakage Rate**
Torpedoes	0.15
Short Range SSMs	0.10
Long Range SSMs	0.05

Table 2. Offensive Weapon Leakage Rates

E. MEASURE OF EFFECTIVENESS

1. Fractional Exchange Ratio (FER)

The main Measure of Effectiveness (MOE) used in this thesis is FER. It compares the fraction of two forces destroyed by the other under the supposition that they exchange salvos. Mathematically, the ratio of fractional losses after A and B exchange salvos is:

$$FER = \frac{\Delta B / B}{\Delta A / A} \quad (9)$$

FER indicates who wins the salvo exchange or if there is parity with some losses on both sides due to leakers. When FER is greater than one, side A has reduced B by a

greater fraction than B has reduced A. Thus, in a sense, A has won because it will have surviving units when B is annihilated. When FER is less than one, side B has the advantage of the exchange. If FER is between zero and one, B wins, and, if FER is greater than one, A wins. If FER is one, parity is achieved. The use of FER as a MOE is further discussed in later chapters.

2. Remaining Units after a Salvo Exchange

After a salvo exchange, the number of ships out of action is calculated from the embellished Salvo Equations. Naturally, the number of ships put out of action has a lower bound of zero and an upper bound of the initial number of ships. Therefore, the equations have been tailored to provide results within the above-described bounds. Ships put out of action subtracted from the initial number of ships results in the remaining ships, which, along with FER, is used as the second MOE. This thesis looks into encounters and reveals the number of required ships to achieve a Breakpoint and Dominance. To this purpose, a fixed number of side B OPFOR ships is used against a variable number of side A FRIFOR ships: Breakpoint and Dominance are described as follows:

a. Breakpoint

Breakpoint for side A is achieved when the number of remaining A units is strictly greater than the number of remaining B units.

b. Dominance

Dominance for side A is achieved when the number of A units lost is minimized and the number of remaining A units is strictly greater than the number of remaining B units, which is zero.

F. MODEL IMPLEMENTATION

An embellished Salvo Equations Model with multiple aspects has been implemented using Microsoft Office Excel spreadsheet software based on the basic modeling techniques used by Christiansen (2008). Embellished Salvo Equation attributes, and other parameters, are inputted into the file. The input spaces are designed as variables. After a salvo exchange, the results are displayed, namely the FER and the remaining units on both sides. A separate file graphs FER and remaining units from each side, obtained by fixing the number of OPFOR units and varying the number of FRIFOR units. From these graphs, the number of FRIFOR ships required for Breakpoint and Dominance are obtained. These resulting numbers provide an overall conclusion about the scenario and answer the research questions. The scenario is specified in greater detail in the following chapter.

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III. SCENARIO PARTICIPANTS

A. FRIENDLY FORCE SCENARIO

This thesis’ scenario is an encounter of U.S. ships and Iranian forces in the Strait of Hormuz. However, its littoral environment is easily applicable to many other regions, nations, and non-governmental organizations around the world. The scenario’s outcome is to depict littoral warfare operations in a confined area where there are numerous islands and bays that provide havens for small boat operations. These operations are deadly for many conventional ships. Navies around the world, therefore, are adopting smaller, lighter, cheaper, yet stealthier and capable ships to overcome multi-axis threats. These are mostly asymmetric and do not occur in blue waters.

USS Freedom, or LCS, compared to destroyers or cruisers, is considered a capable candidate for this job with her numerous air assets, lower signatures, and proposed lower cost (CRS Report, 2008). However, is LCS the best design, or could another ship provide similar or better performance at lower cost? This scenario considers LCS and five other international ship designs. As discussed, this scenario places a FRIFOR of a LCS squadron within the Strait of Hormuz in support of CSG-ESG operations in the Persian Gulf. The scenario calls for Iran to announce the closure of the Strait to all commercial traffic in response to a perceived threat from Israel. Hostilities commence when the U.S. and the allies challenge the closure. Concurrent allied operations have eliminated

the Iranian Air Force, shore-based SSM, and mine threats. What remains at the scenario start is a robust Iranian littoral threat.

Eleven types of Iranian naval vessels are considered. Each carries missiles or torpedoes including one carrying both. There are two classes of conventional and midget subs (both carrying torpedoes); two classes of missile carrying FPBs; three classes of fast missile boats; and four classes of fast torpedo boats. With the exception of submarines, they are all very fast. Except for the FPBs and the Kilo class submarines, they are all fairly new and assumed to be problem-free (Jane’s Fighting Ships, 2009). Larger classes of ships are either obsolete or assumed to have been previously destroyed. Non-missile or torpedo-carrying boats are not applicable to the scenario, since they are in-shore players and, away from shore, pose no lethal threat.

FRIFOR ships are composed of a LCS SAG. To form a squadron level Task Force, soon the SAG will be reinforced by other LCSs. This Task Force will be positioned inside the Strait around the strategic Iranian naval bases. They will be ready to neutralize adversarial Iranian ships that are intent upon attacking traffic transiting through the Strait. As before, East-West traffic is to continue transiting the Strait. The shipping lanes, however, are shifted further south, just off the territorial water lines of Oman and U.A.E. This is to keep the traffic away from the attackers’ target acquisition range. FRIFOR ships operate inside a buffer zone between Iranian bases and the shipping lanes.

At first, the FRIFOR squadron will be comprised only of LCSs. After this engagement is modeled, five other candidate frigates and corvettes take LCS’s place and are modeled. The results are displayed and each candidate ship is compared and evaluated.

B. FRIENDLY FORCE CANDIDATES

For model simplification, each candidate is assumed to use the MH-60R Seahawk helicopter, or a variant, as the helicopter type, allowing the focused comparison of ships, not the aircraft. Detailed information on FRIFOR candidate ship designs has been compiled from the websites of *Jane’s Fighting Ships* (2009) and *Naval Technology* (2009) and is in Appendix A. Model Assumptions are in the next chapter. The following two tables represent general characteristics and weapon capabilities of the FRIFOR candidate designs. It is assumed that all ships have sonar capability for ASW.

Class	**Year**	**Length**	**Draft**	**Weight**	**Speed**	**Crew**
Freedom	2008	115.3 m.	3.9 m.	3089 t.	45 Kts.	50
Formidable	2007	114.0 m.	5.0 m.	3200 t.	27 Kts.	86
MILGEM	2011	99.0 m.	3.8 m.	2000 t.	29 Kts.	93
Steregushchiy	2007	104.5 m.	3.7 m.	2200 t.	26 Kts.	100
Sigma	2007	90.7 m.	3.6 m.	1692 t.	28 Kts.	80
Visby	2006	73.0 m.	2.4 m.	620 t.	35 Kts.	43

Table 3. General Ship Design Characteristics.

Class	**SSM**	**SAM**	**PDMS**	**Gun**	**CIWS**	**Torpedo**
Freedom	-	-	21	57 mm	-	-
Formidable	8	32	-	76 mm	-	6
MILGEM	8	-	21	76 mm	-	4
Steregushchiy	-	-	8	100 mm	4	8
Sigma	4	-	8	76 mm	-	6
Visby	8	-	-	57 mm	-	4

Table 4. Ship Weapons Capabilities.

1. Freedom Class LCS

The first candidate for the Task Force is USS Freedom. Since the tri-hull USS Independence has essentially the same capabilities as USS Freedom, she will not be considered as a separate alternate. Freedom is a medium size frigate, with significant stealth features and lower signatures built for littoral warfare operations. The main characteristics of the ship include mission packages to be carried based on the required mission. Depending on the mission package, two organic aircraft embarkation schemes are available: two MH-60R Seahawk helicopters, or one MH-60R Seahawk, and three MQ-8B Fire Scout UAVs.

LCS has no SSMs and must rely on the ASUW mission package component weapons: Seahawk helicopters in an ASUW role carrying AGM-114 Hellfire missiles to provide surface weapons. Similarly, the ship has no torpedoes and relies on the ASW mission package component weapons: Seahawk helicopters in an ASW role carrying Mk-54 torpedoes. SAM

capability is limited to RAM (Rolling Airframe Missile) PDMS. Although LCS lacks ship-borne weapons, except for a superb dual-purpose deck gun, her two helicopters are a significant feature and will have an impact on the outcome in LCS encounters. Open-source intelligence suggests that the unit cost of an LCS is approx. $400 million. Recently, however, this seems likely to increase.

2. Formidable Class Frigate

An alternative to the LCS is the newly built Singaporean Navy Formidable Class frigate built for operations in the Strait of Malacca and the South China Sea. It is also a medium-size frigate with great stealth features. Formidable is designed based on French naval technology and enhanced with Singapore's indigenous efforts. Formidable is a typical frigate with a full weapons suite and one Seahawk. Open-source intelligence suggests that the unit cost of a Formidable is approximately $300 million.

3. Milli Gemi (MILGEM) Class Corvette

Turkish Navy ship building efforts have produced the Milli Gemi (National Ship) or MILGEM corvette in 2008. Basically a smaller version of Formidable in many aspects, MILGEM is considered a large corvette built with mainly indigenous efforts. This includes the Command and Control (C2) system. The difference between MILGEM and Formidable, other than the obvious size, weight, and price, is that MILGEM relies on RAM PDMS for AAW, similar to the LCS. Otherwise, both hold the same low signatures and stealth features as well as the same Seahawk helicopter. Built for

operations mainly in the Aegean Sea and Eastern Mediterranean, a MILGEM unit cost, based on open-source intelligence, is predicted to be approximately $200 million.

4. Steregushchiy Class Frigate (Russian LCS)

Also known as the Russian LCS, Steregushchiy, although built for the same purpose, differs from the LCS in design and operational responsibilities. Built as part of the traditional Russian fleet, where every ship has a different significant duty, Steregushchiy is not quite as independent a player as Freedom. For analysis purposes, however, she is considered a candidate as a new ship with a goal towards littoral warfare operations. Steregushchiy lacks SSMs, but does have torpedo launchers as well as one Seahawk-like aircraft. Design features are relatively poor compared with other classes, but she represents a conventional light frigate built for littoral operations. Open-source intelligence suggests that the unit cost of the export version of a Steregushchiy is approximately $150 million. Although the Steregushchiy is less expensive than other alternatives, the MOE is the number of required ships. Therefore, unit cost is a relative issue mainly influenced by the differences in the technology and the market of shipbuilding countries.

5. Sigma Class Corvette

In an effort to modernize its navy, Indonesia has recently built Sigma Class corvettes in Dutch shipyards. Similar to the purpose of Formidable, Sigma corvettes are to provide maritime security in Strait of Malacca and

Southeast Asia. A typical corvette, Sigma has a full weapons suite. Her air defense, however, relies on a less effective PDMS. The main difference between this corvette and other alternatives is its inability to house a helicopter in a hangar due to size. Although lacking this capability reduces the cost and manpower, it decreases the ship’s performance due to the type of the helicopter and the helicopter’s reduced endurance during foul weather conditions. Due to her lack of a hangar, smaller size, and other constraints, it is assumed that Sigma is to carry a Seahawk-like variant, precisely the same helicopter but with less Hellfire and Mk-54 load. Open-source intelligence suggests that the unit cost of a Sigma is approximately $200 million.

6. Visby Class Corvette

Built for Baltic Sea operations against an obvious threat, the Swedish Visby is doubtless one of the world’s few fully stealth-capable ships that is actively operational. Smaller in displacement and length than the other candidates, it is foreseen as an extremely capable asset in littoral operations. Of all the candidates, Visby has the best stealth features. Although she lacks an AAW capability, she relies on the stealth and the same gun that LCS has for defense. Similar to Sigma, with no hangar for helicopter, she supports one helicopter of a Seahawk variant. Open-source intelligence suggests that the unit cost of a Visby is approximately $200 million.

C. OPPOSING FORCE THREAT ASSESSMENT AND ASSUMPTIONS

According to worldwide intelligence centers, the navy is Iran’s most strategically important military service (Jane’s Sentinel Security Assessment, 2009). The Iranian Navy is rebuilding and modernizing itself along with Iran’s other programs focusing on nuclear weapons and long-range ballistic missile building efforts. As most of Iran’s oil exports and trade pass through the Strait of Hormuz, the vital importance of the Persian Gulf for Iran is an obvious reason for its effort to modernize the navy after the Iran-Iraq war (Ripley, 2008). Iran’s technology transfer from China, North Korea, and Russia is well known. In addition, its indigenous shipbuilding efforts have, in recent years, proven fruitful (Fish, 2008; Gelfland, 2008).

Along with Iran’s efforts towards building long-range ballistic missiles, anti-ship missiles based on Chinese technology pose a significant threat in the Persian Gulf. Chinese C-802 missiles are claimed to be a reverse-engineered Exocet missile (Federation of American Scientists, 2009; Global Security.Org, 2009). They have been re-engineered by Iran and put into service as upgrades to their navy’s aged and unmaintained Harpoon missiles. The missiles have also been placed onto the new fast missile boats that were built in Iran. Besides the C-802, short-range Chinese SSMs, C-701 or FL-10s, are also re-engineered in Iran. These are becoming the main assault weapons of the newly built fast (50 knots or over) and small boats (Jane’s Fighting Ships, 2009).

The new Iranian small boats, with almost no RCS and very high speeds, pose a significant threat to FRIFOR

operating close to Iranian shores in the Strait of Hormuz. Although these boats do not carry long-range SSMs, their local knowledge of the waters and high-speed capabilities give them the advantage in delivering their short-range SSMs at required distances. As mentioned, some of these boats are not missile-capable, but are torpedo-capable. Although Iran’s capability to deliver a torpedo strike is uncertain, the effect of a torpedo hit due to its heavy warhead makes it a serious threat. The fact that some of these boats are semi-submersible brings the possibility of OPFOR boats approaching closer distances undetected.

1. Iranian Naval Force Review

Table 5 outlines the Iranian Navy OPFOR surface and sub-surface capability. Large naval assets, such as frigates, corvettes, amphibious ships, auxiliary ships and all obsolete ships are excluded. Naval air assets and small inshore boats with no missile or torpedo capability are also excluded. It is an assumption that either the Iranian Navy’s obsolete assets will pose almost no threat or the bigger ships will have already been taken out in previous operations and aircraft strikes. The remaining forces from the Iranian Navy include the submarines and the smaller, newer and faster boats with lethal weapons. Iranian Caspian Fleet vessels are also not considered. After careful consideration of the strength of the Iranian Navy based on the latest intelligence from open sources, it is assumed that the Iranian Navy’s lethal combatant strength is within the following classes and numbers shown in Table 5. Detailed information regarding each class is compiled from the websites of *Jane’s Fighting Ships* (2009), *Federation of*

American Scientists (2009) and *Global Security.Org* (2009) and displayed in later sections and in Appendix B.

Submarines (Subs) **SSK/SSC**	**Fast Patrol Boats (FPBs)** **PGFG**	**Small Missile Boats** **PTG**	**Small Torpedo Boats** **PTF**
3 x Kilo	10 x Kaman	10 x Mk 13	10 x Tir
5 x Yono	10 x Thondor	5 x C-14	15 x Peykaap I
		25 x Peykaap II	3 x Kajami
			3 x Gahjae

Table 5. Iranian Naval Forces Strength.

2. Iranian Naval Bases

Iran has numerous operational naval bases that control the entire Persian Gulf, Strait of Hormuz, and outside the Gulf of Oman. After careful consideration of the open source intelligence concerning Iranian naval bases, their locations, operational status, and Google Earth imagery, it is deduced that Iran has the operational naval bases shown in Table 6 (Jane’s World Navies, 2009; Jane’s Fighting Ships, 2009; Global Security.Org, 2009; Military Net, 2009).

Very Large Naval Bases	**Large Naval Bases**	**Medium Naval Bases**	**Small (Island) Naval Bases**
Bandar Abbas*	Bandar Lengeh*	Qeshm Island*	Larak Island*
Bushehr	Bandar Beheshti	Jask**	Abu Musa Island*
	Bandar Khomeini	Kharg Island	Sirri Island**
		Khorramshahr	

Table 6. Iranian Naval Bases.

* These naval bases are located inside the Strait of Hormuz.
** These naval bases are located just outside of the Strait.

Bandar Abbas is the largest and most strategically-located naval base in Iran. It sits on the mainland in the north of the Strait of Hormuz, just over 30 NM from the center of the shipping lanes. It is the headquarters of the Iranian Navy and responsible for the 1st Naval District. A major portion of Iranian shipbuilding facilities and dockyards are located here as well as many major naval assets. Kilo class submarines are known to be stationed in Bandar Abbas. Recently, however, it was decided to move them to Bandar Beheshti where they can reach high seas without obstruction. The second largest base is Bushehr. It is located on the mainland in the middle of Persian Gulf and is responsible for 2nd Naval District.

Another large base is Bandar Lengeh, which controls the Persian Gulf entrance of the Strait. As previously mentioned, Bandar Beheshti is the newly-designated

submarine base in the Gulf of Oman. Bandar Khomeini is located in the oil-rich Basra region.

Of the medium-sized bases, the most important is Qeshm Island, which is strategically located inside the Strait of Hormuz. It is an island practically connected to the mainland and it forms an extension deep into the Strait. Jask is the newest naval base on the Gulf of Oman entrance of the Strait and it is built to better control shipping lanes. Kharg Island is an island base located in a major offshore oil region in the middle of the Persian Gulf. Lastly, Khorramshahr, located in the Basra region, sits on the border of Iraq.

The three small island bases are typical piers designed to support small naval assets. Larak Island is right in the Strait’s heart and Abu Musa Island, although disputed by U.A.E., is in the western entrance of the Strait. Sirri Island is just outside the Strait and further west from the previous two islands.

3. Iranian Naval Base Asset Allocation

Considering the Iranian oil drilling and processing sites, major trade routes, geopolitically important strategic locations, such as the Strait of Hormuz, the ongoing U.S. and coalition exercises and operations in and outside of the Persian Gulf, it is assumed that the strength of the Iranian Navy is distributed as depicted in Table 7. This assumption is made after current known locations of the Iranian Naval assets, excluding the Caspian Fleet, have been investigated using open-source intelligence, i.e., Google Earth. It is understood that this assumption is only for analytical purposes and is

subject to major debate regarding where the Iranian administration and Naval leaders would choose to locate their naval assets if this scenario were to transpire.

Naval Base	**Submarines**	**PGFG**	**PTG**	**PTF**
Bandar Abbas	2xKilo 3xYono	6xKaman	2xPeykaap II	
Bushehr	2xYono	4xKaman	2xPeykaap II	
Bandar Lengeh		4xThondor	3xC-14 3xPeykaap II	
Bandar Beheshti	1xKilo	4xThondor	2xMk 13 2xPeykaap II	
Bandar Khomeini		2xThondor	2xMk 13 2xPeykaap II	
Qeshm Island			2xMk 13 2xC-14 2xPeykaap II	2xTir 3xPeykaap I
Jask			2xMk 13 2xPeykaap II	2xPeykaap I
Kharg Island			2xMk 13 2xPeykaap II	2xTir 2xPeykaap I
Khorramshahr			2xPeykaap II	2xPeykaap I
Larak Island			2xPeykaap II	2xTir 2xPeykaap I 2xKajami
Abu Musa Island			2xPeykaap II	2xTir 2xPeykaap I 1xKajami 1xGahjae
Sirri Island			2xPeykaap II	2xTir 2xPeykaap I 2xGahjae

Table 7. Iranian Naval Base Asset Allocation.

D. OPPOSING FORCE SCENARIO

In this section, the OPFOR operational plans and FRIFOR scenario merge together and create the modeled scenario. There are a total of seven Iranian bases in and around the Strait of Hormuz. The total number of assets allocated to these bases is 64 ships. Inside the Strait of Hormuz, there are three centrally located Iranian Bases. Two other bases are on the western Persian Gulf entrance of the Strait, as depicted in Figure 1.

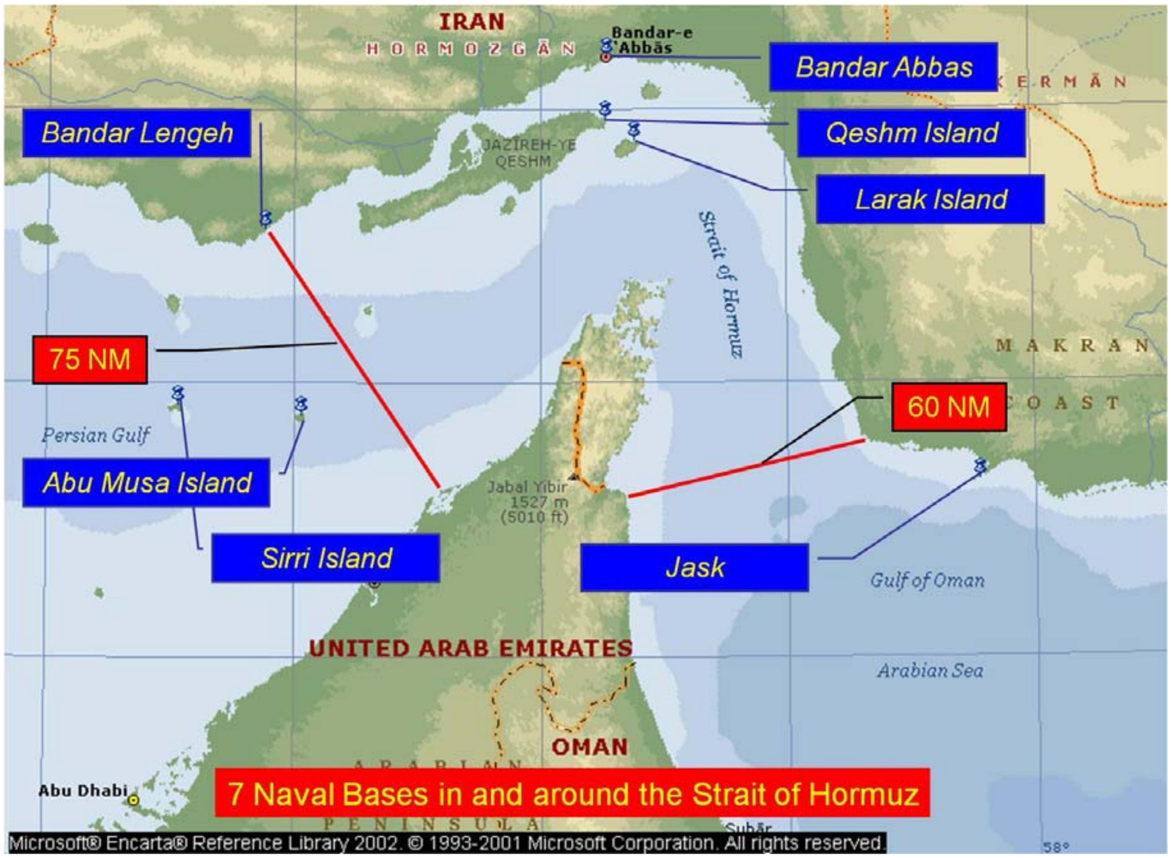

Figure 1. Strait of Hormuz and Vicinity, after Microsoft Encarta.

To focus the scenario and the model into a higher-resolution geographic area, two bases, Sirri Island and Jask, have been omitted from the OPFOR scenario. As a

result, only five bases with a total number of 50 allocated assets are considered. This includes primarily Bandar Abbas, Qeshm Island, Larak Island, Bandar Lengeh and Abu Musa Island. The first three bases are located in the central Strait; the latter two are on the west, as depicted in Figure 2. Detailed high resolution Google Earth pictures of these five bases that display piers and ships have been investigated closely to understand the OPFOR Order of Battle.

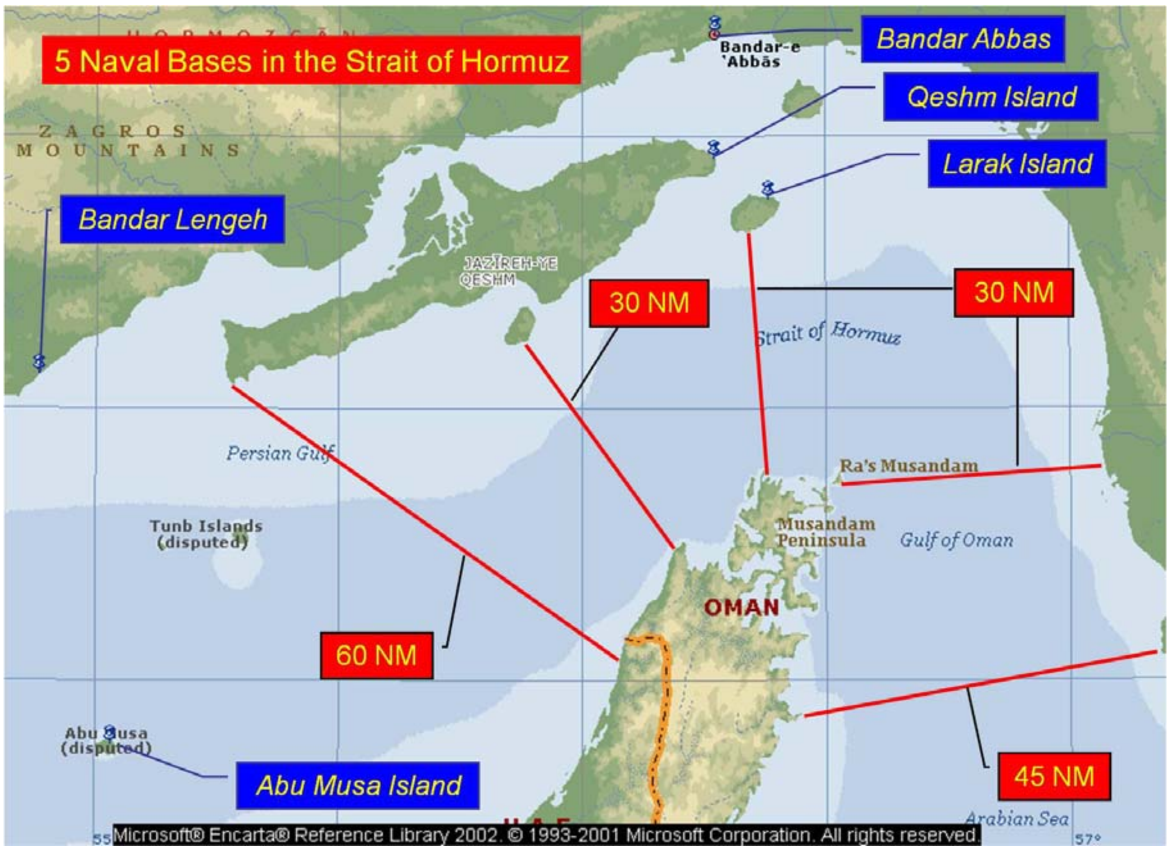

Figure 2. Scenario Naval Bases in Strait of Hormuz, after Microsoft Encarta.

Based on the locations of the bases, Iranian Naval Forces are divided into two groups. Therefore, the threat to FRIFOR is expected from two different areas: the Central

Strait area, with three bases that hold 32 Iranian naval assets, and the western Strait area, with two bases that hold 18 assets. Considering this geographical separation, the engagements modeled by Hughes’ Salvo Equations are assumed to occur in two different places simultaneously. FRIFOR Squadron is to be divided into two groups. This allows an encounter with two OPFOR groups.

The engagements are to take place in the following order. The first attackers from Iranian bases will be the submarines. When hostilities start, the Kilo Class submarines are expected to be in the central part of the Strait ready to sink any tanker, merchant, or any enemy naval vessel. The second wave of attackers is expected to be the FPBs. After the larger ships of the Iranian Navy have been destroyed, FPBs remain the largest of the OPFOR ships. They all have C-802 long-range SSMs. When the hostilities commence, they are expected to encounter the FRIFOR squadron following their submarines.

The expected third wave is the Yono Class midget submarines. Because of their small size and shore support dependence, they are not expected in open seas, but pose a threat in the Strait. The remainder attacker waves include PTGs with short range SSMs and PTFs with lightweight torpedoes. These two groups of boats are fast, but, since they are very small, they are restricted to the inshore zone. Therefore, they will be the last two waves of attackers as the FRIFOR squadron proceeds forward towards the Iranian mainland. PTFs attack last, as they are considered the Iranian Navy’s last resort since they only fire torpedoes and need to be close to their targets.

Summarizing, there are two engagement regions and a total of five waves of attackers. The Salvo Model is to reveal the number of FRIFOR ships needed for Breakpoint and Dominance for each encounter given the number of OPFOR. Therefore, FRIFOR is divided into two squadrons and the force sizes become model variables. The OPFOR is assumed to be structured into the following Task Force (TF) and Task Groups (TG). TF 480, composed of five TGs and a total of 32 ships, operates out of Bandar Abbas, Qeshm Island, and Larak Island. TF 490, composed of 3 TGs and 18 ships, operates out of Bandar Lengeh and Abu Musa Island. Table 8 shows the OPFOR Order of Battle which operates from five bases within two TFs.

TF 480	**Units**	**TF 490**	**Units**
TG 480.01	***SSK*** 2 X Kilo	***TG 490.01***	***PGFG*** 4 x Thondor
TG 480.02	***PGFG*** 6 x Kaman	***TG 490.02***	***PTG*** 3 x C-14 5 x Peykaap II
TG 480.03	***SSC*** 3 x Yono	***TG 490.03***	***PTF*** 2 x Tir 2 x Peykaap I 2 x Kajami 1 x Gahjae
TG 480.04	***PTG*** 2 x Mk 13 2 x C-14 6 x Peykaap II		
TG 480.05	***PTF*** 4 x Tir 5 x Peykaap I 2 x Kajami		

Table 8. OPFOR Order of Battle.

E. OPPOSING FORCE ASSETS

Detailed information on each class of OPFOR ships and their weapons is in Appendix B. For modeling purposes, all PTGs are assumed to carry Iranian C-701 Kosar short-range SSMs built based on Chinese technology, although some carry the similar Chinese FL-10s. All PTGs and PTFs have speeds of 50 knots or over, weights of 30 tons or less, and lengths of 21 meters or less.

1. Kilo (Project 877 EKM) Class Submarine (SSK)

The Iranian Navy has three Russian-built Kilo-class conventional submarines. Although it is reported that these submarines underwent major refit under Russia's supervision, including the addition of Russian ASCMs, this update is not confirmed and is omitted from the model (Jane's Underwater Warfare Systems, 2009). A typical diesel submarine, Kilo-class carries 18 heavyweight (533 mm) torpedoes. The submarines' mine-laying capability is not considered in the model. Reports of their transfer to base in the Gulf of Oman have been confirmed but, for the sake of the scenario's applicability to the rest of the world and to increase the number of threat axis, two Kilo class boats are included in the model.

2. Yono (IS 120) Class Coastal Submarine (SSC)

Based on North Korean midget submarine technology, the recently-built five Yono class boats are very small and shore-support dependent. They are designed for littoral waters and can deliver at least two torpedoes. They are

considered to be built as covert weapons to strike vessels in the Strait of Hormuz (Jane’s Underwater Warfare Systems, 2009).

3. Kaman (Combattante II) Class FPB (PGFG)

Built in the late 1970s and early 1980s in France and recently in Iran, these 13 ships are the stronger half of the main missile force on which the Iranian Navy relies on during a conflict in their territory. Having been maintained and their weapons upgraded to include four C-802s, they pose a serious threat to any vessel operating in or around the Strait of Hormuz. Iran has built the last three with indigenous efforts. They are, however, based in the Caspian Sea.

4. Thondor (Houdong) Class FPB (PGFG)

Ten Thondor class FPBs were built by China in the 1990s and, along with Kaman class FPBs, they form the long-range SSM capable force of the Iranian Navy. Armed with four C-802s, they are another formidable threat facing FRIFOR.

5. Mk 13 Class Patrol Boat (PTG)

Built by China, ten Mk 13 boats were recently delivered to Iran, armed with two FL-10 short-range SSMs and two lightweight torpedoes. For modeling consistency, FL-10s and lightweight torpedoes are assumed equivalent to C-701 short-range SSMs.

6. C-14 Class Patrol Boat (PTG)

Similar to Mk 13, the Chinese built C-14s carry four Fl-10 missiles. Nine were delivered starting early in the 2000s; five are missile-capable and the rest are designed as inshore craft.

7. Peykaap II (IPS 16 Mod) Class Patrol Boat (PTG)

Twenty-five Peykaap II boats are believed to have been recently built by Iran based on a North Korean design. Carrying two C-701 SSMs, Peykaap II is a design-improvement of the original Peykaap I. Due to the large number of this class, they pose a serious threat. Small but fast, they are capable boats with very small RCS due to stealthy design.

8. Tir (IPS 18) Class Patrol Boat (PTF)

Another North Korean design, ten Tir-class boats were delivered by North Korea in the early 2000s. Carrying two heavyweight torpedoes in an anti-ship role, Tir certainly increases the dimension of the threat.

9. Peykaap I (IPS 16) Class Patrol Boat (PTF)

Fifteen Peykaap I boats were delivered together with the Tir-class boats. They carry two lightweight torpedoes for ship-disabling role. Their stealthy design features are significant.

10. Kajami Class Semi-Submersible Boat (PTF)

Originally North Korean Taedong-B design high-speed infiltration craft, three of this class were delivered together with Tir-class boats. Very little is known about the design. The concept of operations is likely to include

high-speed surface approach to a target before submerging to a depth of approximately three meters to conduct a torpedo attack using a snort mast.

11. Gahjae Class Semi-Submersible Boat (PTF)

Similar to Kajami, and originally the North Korean Taedong-C design semi-submersible torpedo boat, three of these boats were delivered together with Tir-class boats. Gahjae is based on the Peykaap design and the concept of operations is identical to the Kajami class.

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IV. ANALYSIS AND RESULTS

A. FRIENDLY FORCE MODEL ASSUMPTIONS AND LIMITATIONS

This section outlines the assumptions and limitations of the FRIFOR candidates considered in the model. To determine model parameters, certain assumptions had to be made to allow for ship capability comparisons. The helicopter to be used for all candidates is the MH-60R Seahawk. The assumption for the Seahawk weapon load is either eight Hellfire missiles or four Mk-54 torpedoes. Due to their limited size, capacity and lack of hangar, Sigma and Visby carry a lighter weight Seahawk-like variant. The weapon load for this variant is either four Hellfire missiles or two MK-54 torpedoes. Against PTGs and PTFs, only helicopter-launched Hellfires are used. This is because using Harpoon-like ship-launched long-range SSMs against small boats is not reasonable due to cost and target-allocation schemes.

Defensive power values of the candidates against the enemy SSMs are detailed in Appendix C. For all candidates, defensive power is assumed to be two against the submarines, due to their limited defense against torpedoes, and three against the PTFs. The latter are easier to defend against than submarines. The staying power of all candidates against submarine-launched heavyweight torpedoes is one. Staying power value decisions of the candidates against the rest of the enemy weapons are detailed in Appendix C.

For modeling purposes, the Hellfire missiles fired from FRIFOR helicopters and the C-701s fired from PTGs are

considered equivalent weapons. Similarly, the FRIFOR long-range SSMs (Harpoon, Exocet or RBS) are considered to be equivalent to enemy C-802s. In the ship versus submarine encounters, all the torpedoes, ship or helicopter-launched and submarine-launched, are also considered equivalent.

During encounters, the offensive weapons used by the opposing sides are not necessarily equivalent. For example, LCS fights against all enemy surface ships with helicopter-launched Hellfires; however, the PGFGs return fire with C-802s, PTGs return fire with C-701s, and PTFs return fire with lightweight torpedoes. The model inputs are made to take this into consideration for defensive and staying power. Therefore, not all encounters are homogenous. When a heterogeneous battle occurs, the inputs are made to take into account who is firing what against whom. The details of model input parameters for every encounter and the rest of the Salvo Model parameters for the FRIFOR candidates are discussed in later sections.

For modeling purposes, the LCS mission package concept is not fully taken into account. Against the submarines, LCS has the ASW mission package on board, specifically two helicopters. When the threat changes to surface, the ASUW mission package is in effect, with both helicopters or one helicopter and UAVs, depending on the threat type, PTG/PTF or PGFG respectively. This transition is assumed to occur successfully after each encounter in between waves of OPFOR attackers. During the encounters where helicopters are employed, they are assumed in the air before the salvo exchange commences. They are refueled after each encounter.

Also after each encounter, the ship and helicopter weapons are reloaded. For FRIFOR, every new encounter starts fresh.

1. Freedom Class LCS

In LCS engagements, along with two helicopters, UAVs are used in scouting and targeting, but not in a weapon-delivery role. LCS has no ship-borne striking power (SSMs or torpedoes). LCS operates two helicopters in the air for the ASW role making her striking power eight torpedoes and two helicopters for the ASUW role, against PTG and PTFs, for a striking power of 16 Hellfires. Against the PGFGs, it is assumed that LCS should operate only one helicopter with a striking power of 8 Hellfires. This is due to the larger caliber guns on PGFGs that can target the helicopters within the Hellfire firing range. LCS defensive power is nine against the SSM firing enemy. This is a sum of the 21 cell RAM launcher and a capable rapid-firing 57 mm gun. Staying power against lightweight torpedoes and long-range SSMs is 1.9 and against short-range SSMs is 2.9 due to the difference in warhead sizes. As mentioned, staying and defensive power explanations for FRIFOR ships are in Appendix C.

2. Formidable Class Frigate

Since Formidable is more of a conventional frigate in terms of weapon load, she uses helicopter and/or ship-launched weapons, depending on each encounter. In an ASW role, six ship-launched and four air-launched torpedoes makes a total of 10 for striking power. Against the PGFGs, the striking power is eight Harpoons. Against the small boats, PTGs and PTFs, the striking power is also eight. In

these encounters, however, Formidable uses helicopter-launched Hellfires. Defensive power is nine against the SSM firing enemy for a sum of 32 VLS Aster SAMs and a 76 mm gun. Staying power against lightweight torpedoes and long range SSMs is 1.9 and short range SSMs is 2.9.

3. MILGEM Class Corvette

MILGEM’s striking power is identical to Formidable except the number of torpedo tubes on board is four, which makes the ASW striking power eight. Defensive power is eight against the SSM firing enemy, a sum of 21-cell RAM and a 76 mm gun. Staying power against lightweight torpedoes and long range SSMs is 1.5 and short range SSMs is 2.3.

4. Steregushchiy Class Frigate

Like the LCS, Steregushchiy has no SSMs on board, making the only offensive missile the air-launched Hellfire with a striking power of eight. ASW role striking power is 12 torpedoes, which is a sum of eight tubes on the ship and four torpedoes on the helicopter. Defensive power is 7.7 against a SSM firing enemy, composed of four 30 mm CIWS, eight short-range IR SAMs and a 100 mm gun. Staying power against lightweight torpedoes and long range SSMs is 1.6 and short range SSMs is 2.5.

5. Sigma Class Corvette

Sigma has six torpedo tubes and, combined with the helicopter’s two torpedoes, her ASW striking power becomes eight. In an ASUW role against PGFGs, the striking power becomes four Exocet SSMs on board and, against the small

boats, it becomes four Hellfires from the helicopter. Defensive power is three against the SSM firing enemy, composed of eight short-range SAMs and a 76 mm gun, as explained in Appendix C. Staying power against lightweight torpedoes and long-range SSMs is 1.4 and short range SSMs is 2.1.

6. Visby Class Corvette

Visby has an ASW striking power of six torpedoes, four ship-launched torpedo tubes, and the helicopter's two torpedoes. In an ASUW role against PGFGs, the striking power is eight Swedish RBS SSMs and, against the small boats, it is four Hellfires. Defensive power is two against the SSM firing enemy from the same gun as the LCS, a rapid firing 57 mm gun. Staying power against lightweight torpedoes and long-range SSMs is one and short range SSMs is 1.5.

B. OPPOSING FORCE MODEL ASSUMPTIONS AND LIMITATIONS

As mentioned, OPFOR is expected in the form of two TFs approaching as waves of attackers. In TF 480, there are three classes of PTGs for a total of ten ships forming TG 480.04. Since this TG is attacking as a group, for modeling purposes, they are homogenized as one type of PTG. This homogenization process only affects the striking power of the TG. The rest of the features of each class are almost identical and assumed to be the same. Striking power decision calculations are detailed in Appendix C. Similarly in TG 480.05, there are three classes of PTFs for a total of 11 ships. They are also very similar in design and, since each carry two lightweight torpedoes, no

homogenization is needed and they are assumed to be the same type of PTF. The major threat comes from TF 480 in the heart of the Strait. This is due to the submarines involved and the large number of other vessels.

TF 490 operations in the western part of the Strait are bound to two bases and more limited. Although TF 490 is assumed to attack in three TGs, as previously discussed, it is modeled to attack in two waves. In the first wave, PGFGs and PTGs attack in a combined TG, a combination of four Thondor class PGFG of TG 490.01 and a total of eight PTGs from TG 490.02. The purpose is to swarm the FRIFOR ships, saturating their defense and creating an opening to attack the tankers or other merchant vessels being screened. In this case, the FRIFOR attacks with all the helicopters and ship-born missiles combined regardless of PGFGs stand-off distance and unreasonable expenditure of long range SSMs on small boats. Similar to TG 480.04, TG 490.02 is also homogenized to create the same class of PTGs out of two different classes. Since this combined wave includes PGFGs and PTGs, their striking power (C-802s and C-701s), defensive power (large caliber guns on Thondor classes), and staying powers are homogenized. Detailed calculations are shown in Appendix C. The second wave of TF 490 is TG 490.03, composed of four classes of PTF for a total of six boats, and since they all carry two torpedoes, no homogenization process is needed.

The operational number of total force strength from each base is modified to take into account the maintenance cycle or Operational Defect (OPDEF) of the ships. A 1:5 ratio of unavailable ships is considered and validated by

CAPT Hughes for the Iranian Navy. This depicts that one out of five operational ships of each class is unavailable and in port due to the maintenance cycle or OPDEF. The following information describes the assumptions and limitations of each attacker wave within TFs. The details of model input parameters for every encounter and the rest of the Salvo Model parameters for the OPFOR candidates are discussed in the next section.

1. TG 480.01: Kilo Class SSK

Both Kilo classes that are allocated to operate from Bandar Abbas are involved in the initial wave. The submarine has six torpedo-launching tubes and is given a striking power of six. Defensive and staying power are both one. As mentioned, surface ship versus submarine engagement has not been modeled with Salvo Equations before. Thus, this encounter is expected to give new insights regarding the use of Salvo Equations in ASW. Results displayed in the next chapter show it seems necessary that the submarine threat be eliminated by conventional ASW forces before littoral operations begin. Salvo Equations vividly show the dominance of the submarines in ship versus submarine encounters. It shows that a very small number of submarines can pose a serious threat and a large number of ships are required to dominate the encounter.

2. TG 480.02: Kaman Class PGFG

Also operating from Bandar Abbas, five of the six ships are available. Since they have the long-range SSMs, they are expected to be the second encounter. Striking power is designated as four C-802 long-range SSMs. From the

76 mm gun, defensive power is only two. Staying power is one against long range SSMs and 1.5 against Hellfires.

3. TG 480.03: Yono Class SSC

These midget submarines are also expected out of Bandar Abbas and all three are available. After the initial two waves of attackers as FRIFOR ships move towards the Iranian mainland, Yono classes are expected to pose the third threat. Assumed to be carrying two torpedoes, the striking power is two. Defensive power and staying power is the same as Kilo, one.

4. TG 480.04: PTGs

As the fourth wave of attackers, a total of ten PTGs of three classes from three bases make up this TG, however only eight are available. Their combined striking power is 2.8 C-701s. Defensive and staying power is one.

5. TG 480.05: PTFs

Similarly, a total of 11 PTFs of three classes from two bases make up this TG, however only nine are available. All ships have two torpedoes and given a striking power of two. Defensive and staying power are one.

6. TG 490.01-02: Thondor Class PGFGs and PTGs

The first wave of attack in the western region is the combination of three available Thondor class ships out of four from Bandar Lengeh, and seven available PTGs out of eight from the two western bases. Combined striking power of the two classes of PTGs is 2.9 C-701s and striking power of Thondor is four C-802s. Therefore, total homogenized striking power becomes 3.2. Defensive power of PTGs is one

and due to rapid firing medium caliber guns, Thondor's defensive power is two. Their homogenized defensive power is 1.3. Staying power of this TG is 1.2 against Hellfires and varies between one and 1.2 for the combination of attacking missiles. This is due to Hellfire and SSMs, since not each FRIFOR ship has the same number of SSMs on board or Hellfires on the helicopters.

7. TG 490.03: PTFs

Similar to TG 480.05, a total of six PTFs of four classes from two bases make up this TG; however only five are available. All ships have two torpedoes making a striking power of two. Defensive and staying power are one.

C. MODEL INPUT PARAMETERS

In this section, model input parameters for every encounter are displayed based on the specifications of the vessels detailed in Appendices A and B. Assumptions are made with the approval of CAPT Hughes. For each encounter, targeting/scouting effectiveness, defender readiness/ alertness and training effectiveness are also shown. For base case model runs, seduction and distraction countermeasure effectiveness are not taken into consideration yet; rather, these two parameters are assumed to be one, making no effect on the equations. To determine the number of ships required for Breakpoint and Dominance over OPFOR, the number of FRIFOR units is made a variable. OPFOR numbers are fixed and represent the operational numbers available not in maintenance cycle.

Striking power is the number of weapons available. The number of well-aimed weapons that goes into the equations

is calculated by striking power multiplied by the WLR, which is 0.9 for all FRIFOR and OPFOR, and the WHP, which is different for all weapon types as explained in Chapter II. Leakage rates that directly affect the results in the number of remaining units are also explained in Chapter II. Defensive and staying power calculations of FRIFOR are explained in Appendix C. OPFOR training effectiveness is always 0.95; whereas, FRIFOR's, due to superior training by assumption, is one. Defensive readiness of OPFOR is always one due to regional expertise and the surprise effect on their behalf. The accumulated results of every encounter are displayed in the next section. The following tables show the model input parameters of six candidate designs versus seven waves of attackers in two TFs, resulting in a total of 42 different engagements. The first five encounters represent the battle against TF 490 in the center of the Strait of Hormuz. The remaining two are against TF 480 in the western entrance to the Strait.

1. FRIFOR vs. 2 x Kilo SSK (TG 480.01)

Both sides are firing torpedoes at each other, which results in a staying power of one for all ships. The Kilo has six torpedo tubes. The ships attack combined with their single helicopters or, in Freedom's case, with two ASW helicopters. Defensive power of surface ships is two due to greater defensive maneuverability. Kilo has no defensive weapons and her targeting effectiveness is one due to her Situational Awareness (SA) superiority. Due to having two helicopters, Freedom has better targeting effectiveness and defensive readiness than other surface ships.

Attribute	Force						
	Freedom	Formid.	MILGEM	Stere.	Sigma	Visby	*Kilo*
Number of Units	Var.	Var.	Var.	Var.	Var.	Var.	2
Striking/Offensive Power	8	10	8	12	8	6	6
Defensive Power	2	2	2	2	2	2	1
Staying Power	1	1	1	1	1	1	1
Targeting/Scouting Effectiveness	0.9	0.85	0.85	0.85	0.85	0.85	1
Defensive Readiness/Alertness	0.9	0.85	0.85	0.85	0.85	0.85	1
Training Effectiveness	1	1	1	1	1	1	0.95
WHP	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Leakage Rate	0.15	0.15	0.15	0.15	0.15	0.15	0.15

Table 9. FRIFOR vs. 2 x Kilo Model Parameters.

2. FRIFOR vs. 5 x Kaman PGFG (TG 480.02)

Five Kamans are operational out of the available six and each has four C-802 SSMs for a striking power of four. 76 mm main gun and other guns result in a defensive power of two. Staying power is one against long-range SSMs and 1.5 against Hellfires. All FRIFOR ships except for Freedom and Steregushchiy attack with SSMs only. No helicopters are used due to Kaman's gun standoff distance. Freedom and Steregushchiy, however, lack SSMs and they, therefore, must rely on ASUW helicopters. Freedom uses only one helicopter due to the threat mentioned above. Helicopters not used for attack are tasked for ISR. Defensive power against enemy

missiles and staying power are calculated as detailed in Appendix C. Regional expertise and surprise effects create a good targeting effectiveness for Kaman, but not as well as Freedom. This is because Freedom uses UAVs for targeting, which provide Freedom a better defensive readiness. Steregushchiy relies on her helicopter for attack and does not have an additional helicopter for ISR. Therefore, she has lower values for targeting effectiveness and defensive readiness.

Attribute	Force						
	Freedom	Formid.	MILGEM	Stere.	Sigma	Visby	*Kaman*
Number of Units	Var.	Var.	Var.	Var.	Var.	Var.	5
Striking/Offensive Power	8	8	8	8	4	8	4
Defensive Power	9	9	8	7.7	3	2	2
Staying Power	1.9	1.9	1.5	1.6	1.4	1	1/1.5
Targeting/Scouting Effectiveness	1	0.95	0.95	0.93	0.95	0.95	0.95
Defensive Readiness/Alertness	1	0.95	0.95	0.93	0.95	0.95	1
Training Effectiveness	1	1	1	1	1	1	0.95
WHP	0.8	0.7	0.7	0.8	0.7	0.7	0.7
Leakage Rate	0.1	0.05	0.05	0.1	0.05	0.05	0.05

Table 10. FRIFOR vs. 5 x Kaman Model Parameters.

3. FRIFOR vs. 3 x Yono SSC (TG 480.03)

This encounter is the same as the Kilo encounter except for the number of Yono class boats and torpedo tubes, which is two. The targeting effectiveness of Yono is slightly less than Kilo due to technical differences. FRIFOR attributes and assumptions are the same as in the Kilo encounter.

Attribute	Force						
	Freedom	Formid.	MILGEM	Stere.	Sigma	Visby	*Yono*
Number of Units	Var.	Var.	Var.	Var.	Var.	Var.	3
Striking/Offensive Power	8	10	8	12	8	6	2
Defensive Power	2	2	2	2	2	2	1
Staying Power	1	1	1	1	1	1	1
Targeting/Scouting Effectiveness	0.9	0.85	0.85	0.85	0.85	0.85	0.95
Defensive Readiness/Alertness	0.9	0.85	0.85	0.85	0.85	0.85	1
Training Effectiveness	1	1	1	1	1	1	0.95
WHP	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Leakage Rate	0.15	0.15	0.15	0.15	0.15	0.15	0.15

Table 11. FRIFOR vs. 3 x Yono Model Parameters.

4. FRIFOR vs. 8 x PTGs (TG 480.04)

Out of ten PTGs in three classes available in this TG, eight are operational. They have a homogenized striking power of 2.8, as derived in Appendix C. TG 480.04 has two

Mk 13 with four C-701s, one C-14 with four C-701s and five Peykaap II with two C-701s. Due to OPDEF, one C-14 and one Peykaap II are disregarded. Since they have no defensive weapons, their defensive power is considered one. Similarly, staying power is one due to their very small size. Their targeting effectiveness is less than PGFGs due to inferior technology. Defensive readiness, however, is one due to their regional expertise and smaller RCS. As mentioned before, FRIFOR is to engage PTGs with helicopters. This is only because Hellfires are more suitable than larger SSMs and there is no threat to helicopters. Freedom will attack with both helicopters, giving her better striking power, targeting effectiveness, and defensive readiness than the other FRIFOR candidates. Sigma and Visby have lighter Seahawk-like helicopters with only four Hellfires as opposed to eight. Since all OPFOR are firing smaller C-701s, the staying power of FRIFOR is greater then in the engagement against PGFGs. Generally, FRIFOR attributes are degraded against PTGs, relative to PGFGs, due to the former’s smaller RCS and regional tactics, such as hiding behinds rocks or islands and the surprise effect.

Attribute	Force						
	Freedom	Formid.	MILGEM	Stere.	Sigma	Visby	*PTG*
Number of Units	Var.	Var.	Var.	Var.	Var.	Var.	8
Striking/Offensive Power	16	8	8	8	4	4	2.8
Defensive Power	9	9	8	7.7	3	2	1
Staying Power	2.9	2.9	2.3	2.5	2.1	1.5	1
Targeting/Scouting Effectiveness	0.95	0.9	0.9	0.9	0.9	0.9	0.9
Defensive Readiness/Alertness	0.95	0.9	0.9	0.9	0.9	0.9	1
Training Effectiveness	1	1	1	1	1	1	0.95
WHP	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Leakage Rate	0.1	0.1	0.1	0.1	0.1	0.1	0.1

Table 12. FRIFOR vs. 8 x PTG Model Parameters.

5. FRIFOR vs. 9 x PTFs (TG 480.05)

Eleven PTFs in three classes are available in the center of the Strait, but only nine are operational with a striking power of two torpedoes. There are three Tir with two heavyweight torpedoes, four Peykaap I and two Kajami semi-submersible boats with two lightweight torpedoes each. One Tir and one Peykaap I are eliminated due to OPDEF. Tir’s heavyweight torpedoes are assumed to be the same as the lightweight torpedoes. Other than the number of units and striking power, the rest of the attributes are the same as for PTGs, except for WHP and Leakage Rates. This is due to different offensive weapons. FRIFOR’s offensive,

defensive and other attributes are very similar to the previous encounter against PTGs. The main difference is that the staying power is less. This is due to FRIFOR being attacked by torpedoes. Defensive power is three for all FRIFOR ships. Due to an early detection possibility, this is better than against submarines. Defensive readiness of the higher speed ships, Freedom and Visby, is better than the other FRIFOR candidates.

Attribute	Force						
	Freedom	Formid.	MILGEM	Stere.	Sigma	Visby	*PTF*
Number of Units	Var.	Var.	Var.	Var.	Var.	Var.	9
Striking/Offensive Power	16	8	8	8	4	4	2
Defensive Power	3	3	3	3	3	3	1
Staying Power	1.9	1.9	1.5	1.6	1.4	1	1
Targeting/Scouting Effectiveness	0.95	0.9	0.9	0.9	0.9	0.9	0.9
Defensive Readiness/Alertness	1	0.9	0.9	0.9	0.9	0.95	1
Training Effectiveness	1	1	1	1	1	1	0.95
WHP	0.8	0.8	0.8	0.8	0.8	0.8	0.9
Leakage Rate	0.1	0.1	0.1	0.1	0.1	0.1	0.15

Table 13. FRIFOR vs. 9 x PTF Model Parameters.

6. FRIFOR vs. 10 x PGFG-PTGs (TG 490.01-02)

This encounter is envisioned to demonstrate a desperation attack by the Iranian naval forces. All

missile-firing ships of the Iranian naval forces from the western part of the Strait are combined to create a missile-swarm against FRIFOR. In this case, FRIFOR is to attack back with missiles on ships and helicopters combined. This is regardless of consideration of weapon and target proportionality and PGFG gun standoff distance. Three operational Thondor-class PGFGs out of four ships and seven operational PTGs out of eight form this combined OPFOR TG. One Thondor and one Peykaap II are eliminated due to OPDEF.

The combined homogenized striking power of C-802 firing PGFGs and C-701 firing PTGs is 3.2, as explained in Appendix C. These missiles are considered the same for the calculations. Their effect, however, for FRIFOR is factored in as described below. Homogenized WHP and Leakage Rate values for these two types of missiles combined are 0.76 and 0.08 respectively. The defensive power of Thondor is two, due to one 30 mm gun, and for PTG it is one. When homogenized the defensive power becomes 1.3. The staying power of Thondor and PTG is one for all SSMs, but 1.5 and 1 against Hellfires, respectively. When combined, the homogenized value becomes 1.2 if attacked by helicopters only and 1.1 if attacked by ships and helicopters combined. Both defensive and staying power calculations can also be found in Appendix C. Freedom attacks with two ASUW helicopters; Steregushchiy attacks with one ASUW helicopter; the rest of the candidates attack with ship and helicopter combined. The staying power of FRIFOR is calculated with the effect of an incoming mixture of enemy missiles. Targeting effectiveness and defensive readiness differ against PGFG and PTG combined. The value, however,

is homogenized. As with OPFOR, when FRIFOR attacks with ship and helicopter combined, WHP and Leakage Rate change to reflect differing weapon types.

Attribute	Force						
	Freedom	Formid.	MILGEM	Stere.	Sigma	Visby	*PGFG-PTG*
Number of Units	Var.	Var.	Var.	Var.	Var.	Var.	10
Striking/Offensive Power	16	16	16	8	8	12	3.2
Defensive Power	9	9	8	7.7	3	2	1.3
Staying Power	2.5	2.5	2	2.2	1.8	1.3	1.1/1.2
Targeting/Scouting Effectiveness	0.97	0.92	0.92	0.91	0.92	0.92	0.95
Defensive Readiness/Alertness	0.97	0.92	0.92	0.91	0.92	0.92	1
Training Effectiveness	1	1	1	1	1	1	0.95
WHP	0.8	0.75	0.75	0.8	0.75	0.73	0.76
Leakage Rate	0.1	0.08	0.08	0.1	0.08	0.07	0.08

Table 14. FRIFOR vs. 10 x Thondor-PTG Model Parameters.

7. FRIFOR vs. 5 x PTFs (TG 490.03)

Six PTFs in four classes are available, but five are operational in this TG. There are two Tir and one of each from the Peykaap I, Kajami and Gahjae classes. One Peykaap I is disregarded due to OPDEF. Other than the number of units, all attribute values/assumptions of FRIFOR and OPFOR are the same as the fifth encounter against the nine PTFs of TG 480.05.

D. BASE CASE MODEL RUN RESULTS

As specified in Chapter II, the two MOE are the FER and the number of remaining units on both sides. After the model parameters described in the previous section are inputted in an Excel-based Salvo Equations Model, the number of units out of action for both sides (also the number of remaining units) and the FER are obtained for each of the 42 encounters. For this purpose, 42 Excel pages are created to eliminate any error in the modeling sequence. Hence, every encounter has at least one different attribute value. In the base case, the number of OPFOR units is fixed and the number of FRIFOR units is varied. The purpose is to determine the required number of ships for Breakpoint and Dominance of FRIFOR over OPFOR. This is determined by graphing the FER and the number of remaining units for both sides as the Y-Axis over the number of FRIFOR units as the X-Axis.

Recall that Breakpoint is achieved when the number of remaining FRIFOR units is strictly greater than the number of remaining OPFOR units. When the FER is greater than one, FRIFOR reduces OPFOR by a greater fraction. This results in FRIFOR's win over OPFOR. A FER of one is defined as parity when each force causes attrition of the other at equal rates. The number of ships required for Breakpoint is chosen from the integer values of the number of FRIFOR units on the X-Axis. In some cases, parity might continue for a few integer numbers of ships, but as the number of FRIFOR units is increased, at some point the number of remaining FRIFOR units exceeds the remaining OPFOR units.

This integer value of the number of FRIFOR units is accepted as the number of ships required for the Breakpoint with OPFOR.

Dominance is chosen similarly to Breakpoint. In this case, the number of remaining OPFOR ships has to be zero. The number of remaining FRIFOR units has to be maximized or the number of losses minimized (the number of losses can never be zero due to leakers). After that point, the FER has to have a linear increase. This means the minimum FRIFOR loss is achieved and is constant after that point. As the number of FRIFOR units increase, the FER increases as well. Initially, the increase is exponential, but it then r linear as the number of remaining OPFOR units becomes zero and FRIFOR loss reaches the minimum. At this point, when the FER curve becomes linear, the integer value of the number of FRIFOR units is the number of ships required for Dominance over OPFOR. This equates to OPFOR annihilation.

Figure 3 is a visual example of the result of a sample encounter amongst the 42 separate runs. The graph is associated with the Visby versus 10 Thondor-PTG encounter, where Visby and FRIFOR is represented as Force A and OPFOR is represented as Force B. As seen from the graph, if there is one or two Visbys, the result is total FRIFOR annihilation. If there are 3-6 Visby, then parity is achieved with a FER of one, where both forces attrite each other until no ship survives. With seven Visby presents, the remaining number of FRIFOR units is greater than remaining OPFOR units and the FER is strictly greater than one, which is Breakpoint. Then, as the number of Visbys

increase, the remaining number of FRIFOR units gets larger and the FER increases dramatically. Meanwhile, the number of remaining OPFOR units is zero. Dominance, however, is not achieved until out-of-action FRIFOR units are minimized. The number of losses cannot be better than 1.35 in this case, due to the leakage rate, and the FER curve becomes linearly increasing after this point. This happens when there are 11 Visbys, which is the number of ships required for Dominance.

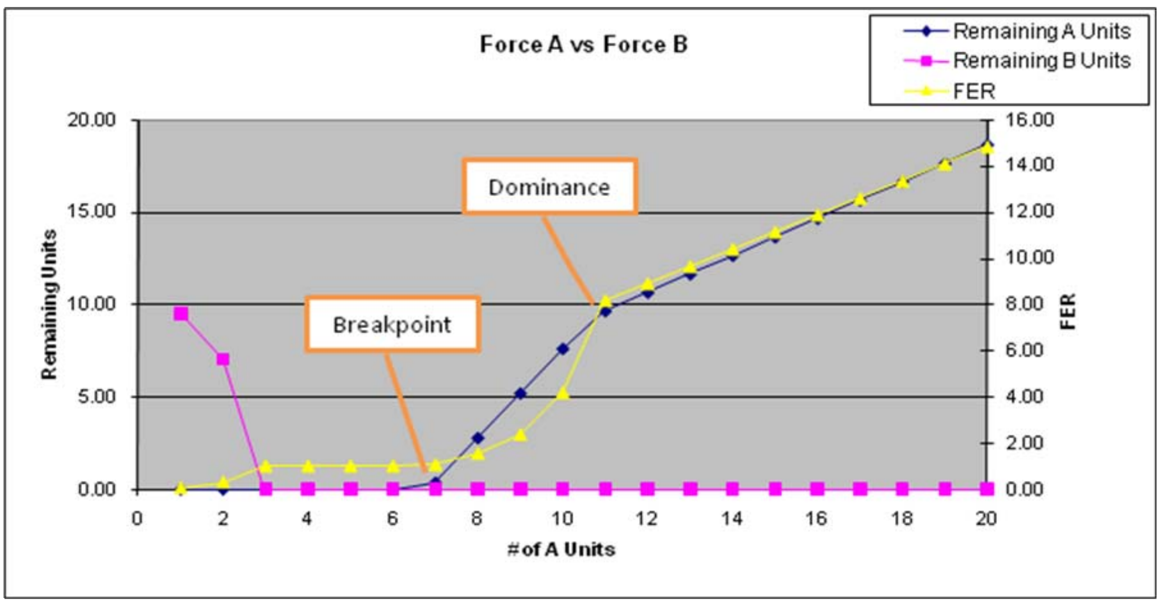

Figure 3. Visby vs. 10 x Thondor-PTG.

Another example is displayed in Figure 4, Freedom versus 5 x Kaman encounter. Force A is FRIFOR or Freedom. In this case, when two Freedoms are present the FRIFOR loss is minimized; the FER is greater than one. However, the number of remaining OPFOR is still greater than the number of remaining Freedoms. When the number of Freedoms is increased to three, it is seen that remaining number of Freedoms is maximized and greater than remaining OPFOR,

which is essentially zero. The FER is already greater than one and is linearly increasing. As a result, at this point, three Freedoms are sufficient for both Breakpoint and Dominance.

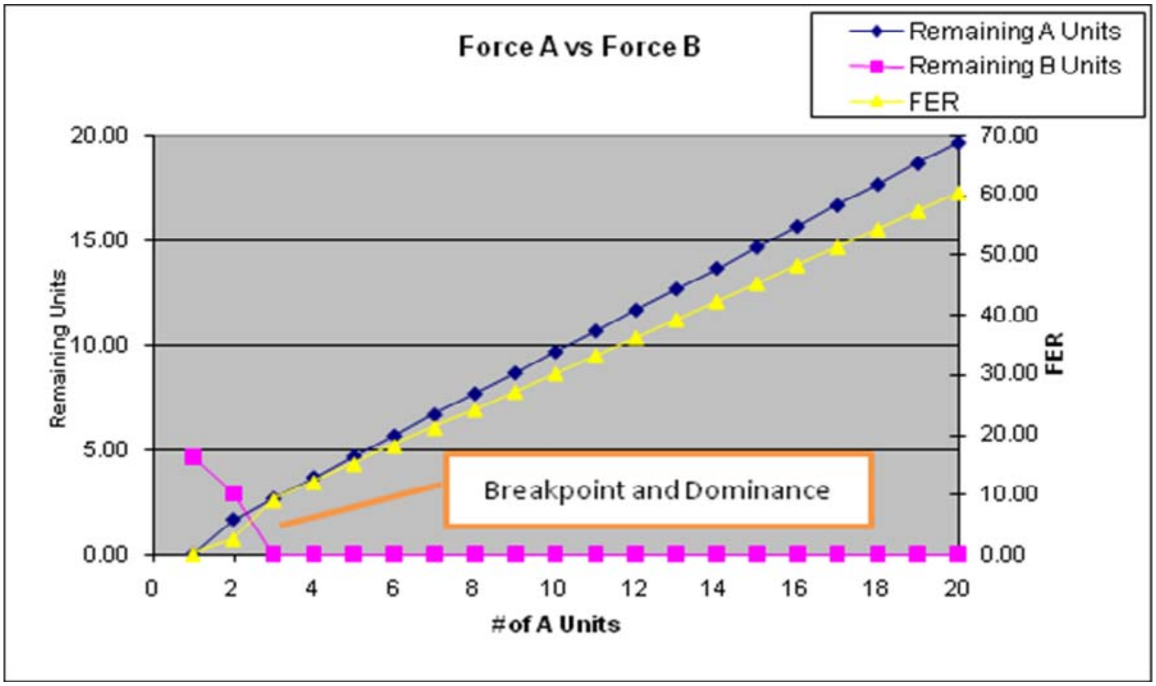

Figure 4. Freedom vs. 5 x Kaman.

Base case runs are conducted with zero countermeasure effectiveness. For each of 42 encounters, the associated FER and remaining units have been graphed. These graphs reveal insightful results for some encounters that have not been modeled using Salvo Equations before, such as surface ship versus submarine encounters. Some results were not predicted and directed further inquiry as shown in the Sensitivity Analysis section. From the 42 encounter results, required numbers for Breakpoint and Dominance are shown in Table 15 for each FRIFOR candidate against each of seven attackers in two different parts of the Strait of

Hormuz, using the FER and the number of remaining ships from both sides within two decimal places.

OPFOR	FRIFOR											
	Freedom		Formid.		MILGEM		Stere.		Sigma		Visby	
	Br.	Do.	Br.	Do.	Br.	Do.	Br.	Do.	Br.	Do.	Br.	Do.
TF 480												
2 x Kilo	4	6	4	6	4	6	4	6	4	6	4	6
5 x Kaman	3	3	3	3	3	3	3	3	5	6	5	6
3 x Yono	2	3	2	3	2	3	2	3	2	3	2	3
8 x PTG	2	2	3	3	3	3	3	3	5	6	6	8
9 x PTF	3	5	4	5	4	5	4	5	5	6	6	6
TF 490												
10 x Thondor-PTG	2	3	3	3	3	3	4	5	5	8	7	11
5 x PTF	2	3	2	3	2	3	2	3	3	4	3	4

Table 15. Base Case Breakpoint and Dominance Requirements.

The results show the required number of FRIFOR ships for Breakpoint and Dominance at each encounter. The question of the total number of FRIFOR ships required in the Strait of Hormuz against OPFOR remains. The Breakpoint results represent the number of ships needed to do just better than parity. In that case, the OPFOR might have been annihilated or the number of remaining FRIFOR units might be almost zero depending on the circumstances and the attributes. Therefore, the total number of ships required for Breakpoint cannot be calculated. Breakpoint results are shown to give decision makers an insight of the minimum

required force in different encounters and circumstances to neutralize the enemy just over parity, but not necessarily to annihilate or dominate. If resources are available the Dominance number gives the best case for any encounter. In a dominant situation, FRIFOR wins, with minimum acceptable losses, and OPFOR is annihilated.

In this thesis, the total number of ships required for Dominance is calculated based on the following assumptions. The first five encounters in Table 15 happen against TF 480 in the center of the Strait. These five waves of attackers are assumed to be encountered in the order of the table’s column. Although dominance is the annihilation of the enemy in an encounter, due to leakers after each encounter, about one FRIFOR ship is taken out of action regardless of the real number (this number could be less than or above one, depending on the encounter, but in general it is about one). For instance, in the case of Freedom, to dominate TF 480’s five waves of attackers, nine ships are required to dominate the threat. If nine ships are initially present in the center of the Strait to battle against TF 480, eight remain after dominating the first wave of Kilos. Normally six ships are enough, but more are required for later waves of attackers. Further, due to leakers, one becomes unavailable so that eight remains for the next encounter. As FRIFOR progresses, if the encounters continue with this logic (enough numbers to dominate each encounter and, after every encounter, only losing one), at the last encounter there will be five ships left to ensure dominance over the nine PTFs.

Domination calculations give the worst case scenario for FRIFOR losses and give a high number of required ships for the mission to annihilate OPFOR. Similarly, TF 490, having two waves of attackers, can be dominated by four Freedoms in the western entrance to the Strait. Thus, the total number of Freedoms required to dominate Iranian Naval Forces in the Strait of Hormuz becomes 13 Freedoms. The numbers for all FRIFOR ships are shown in Table 16.

OPFOR	FRIFOR					
	Freedom	Formidable	MILGEM	Steregushchiy	Sigma	Visby
TF 480	9	9	9	9	10	11
TF 490	4	4	4	5	8	11
TOTAL	13	13	13	14	18	22

Table 16. Base Case Total Number of Ships Required for Dominance.

Based on these total ship requirements for Dominance over OPFOR, associated ranking of the FRIFOR candidate ships is as follows, which is discussed in the last chapter after countermeasure effectiveness have been introduced.

Ranking	Class	Number of Required Ships
1	Freedom	13
2	Formidable	13
3	MILGEM	13
4	Steregushchiy	14
5	Sigma	18
6	Visby	22

Table 17. Base Case FRIFOR Candidate Ship Ranking.

E. HARDKILL CAPABILITY BOOST TO SIGMA AND VISBY

There is a significant difference between the smaller candidates, Sigma and Visby, and the rest of the candidate designs. There are a number of reasons for this. Since these ships are smaller, they do not have a hangar; therefore, they have limited helicopter capability. The lighter version of Seahawk is carried on these ships, which has fewer weapons. Less weapons means less striking power, but there are other factors. Due to smaller length and weight, their staying power is also smaller, especially that of the Visby. For Sigma and Visby in the equations, staying power has a greater impact than striking power. The main problem, however, is that the defensive power of Sigma and Visby is significantly lower than the alternatives. This creates the need for more ships for Dominance.

Due to their poorer defenses, in some cases Sigma and Visby are only slightly better than the OPFOR. Even though

breakpoint numbers are close to the other candidates, Visby and Sigma require more ships to dominate their opponents. In these encounters, defensive power is more important than striking power. Since the enemy has very little defensive capability, if FRIFOR can deny their shots, even FRIFOR's little striking power will do much damage. Sigma has the 8-cell Mistral IR missile launcher as a defensive SAM, which is not a sophisticated defense, and a 76 mm gun. This gives her a defensive power of three. Visby, however, has no SAM and only a capable 57 mm gun. This results in a defensive power of only two.

To bring these two ships to a similar level of performance as the bigger candidates and to reduce the greater requirement for Dominance, it is envisioned that if a 21 cell RAM launcher is added to Sigma and Visby as a hardkill boost, impressive results could be achieved. RAM launcher is chosen since it is a typical defensive PDMS used against SSMs. Many modern navies choose it for their smaller combatants' sole defense. Also, it is a lighter and cheaper system than many SAM launchers, such as Sea Sparrow, and, since it is IR guided, requires less manpower. For modeling purposes, the size, manpower, cost, and RCS of these vessels would not change with the addition of RAM. This is because these changes could be assumed insignificant.

To demonstrate the effects when Sigma has a RAM in place of her Mistral launcher and Visby has a RAM launcher installed onto an appropriate place on the open deck, their defensive powers were changed to eight and nine, respectively, lifting their defensive power relative to the

other candidates. Hardkill added to Sigma and Visby can only affect the encounters against missile firing OPFOR units, PGFGs and PTGs. Table 18 shows the results after the hardkill boost to Sigma and Visby.

OPFOR	FRIFOR							
	Sigma Before HK		Sigma After HK		Visby Before HK		Visby After HK	
	Br.	Do.	Br.	Do.	Br.	Do.	Br.	Do.
TF 480								
5 x Kaman	5	6	**5**	**6**	5	6	**3**	**3**
8 x PTG	5	6	**5**	**6**	6	8	**5**	**6**
TF 490								
10 x Thondor-PTG	5	8	**4**	**5**	7	11	**3**	**3**

Table 18. Breakpoint and Dominance Requirements after Hardkill Boost to Sigma and Visby.

The effects of hardkill and the results are addressed more in the Sensitivity Analysis section. After the hardkill boost, the changes in the total required number of ships for Dominance are shown in bold in Table 19.

OPFOR	FRIFOR			
	Sigma Before HK	Sigma After HK	Visby Before HK	Visby After HK
TF 480	10	**10**	11	**10**
TF 490	8	**5**	11	**5**
TOTAL	18	**15**	22	**15**

Table 19. Total Number of Ships Required for Dominance after Hardkill Boost to Sigma and Visby.

With hardkill boost to Sigma and Visby, the alternatives' requirements of Dominance are shown in Table 20. The required number of ships for Sigma and Visby without the hardkill boost is written in parenthesis.

Ranking	Class	Number of Required Ships
1	Freedom	13
2	Formidable	13
3	MILGEM	13
4	Steregushchiy	14
5	Visby	15 (22)
6	Sigma	15 (18)

Table 20. FRIFOR Candidate Ship Ranking after Hardkill Boost to Sigma and Visby.

F. INTRODUCTION OF COUNTERMEASURE EFFECTIVENESS FOR REAL-TIME APPROXIMATION

In this section, the information provided in the previous section is disregarded and no hardkill improvement has been made to Sigma and Visby. The section continues on from the base case.

Analytical modeling of a real world naval warfare scenario cannot be complete without accounting for countermeasure effectiveness. Measuring countermeasure effectiveness can be challenging with much to be discovered about this phenomenon and its application to naval warfare. The effects of countermeasures in warfare modeling are made difficult by secrecy. A few experts succeeded in providing healthy insights, although many countries (especially the developers) are reluctant to disclose any information about their Electronic Support or Countermeasure capabilities (Kline, 2008). Capturing the effects of Electronic Warfare remains as one of the few warfare areas not fully explored. Unclassified modeling of such warfare is difficult and could be manipulative for intelligence reasons. Basic Salvo Equations do not account directly for countermeasure effectiveness. This study, however, uses the Embellished Salvo Equations solely to model the scenario as realistically as possible.

In Chapter II, seduction and distraction countermeasure effectiveness has been addressed in detail. Base case model runs do not include countermeasure effectiveness. In this section, the details and effects of countermeasure effectiveness are introduced and investigated separately. Modeling countermeasure

effectiveness with the Salvo Equations is complicated. Information on ship design's stealthy features, low signatures, Electronic Support Measure (ESM) and Electronic Countermeasure (ECM) equipments, chaffs, decoys, etc. is not easily obtained. Only basic information is available and the rest is classified. This makes it quite judgmental to assign a value to countermeasure attributes in the Embellished Salvo Equations.

Since assigning mere guessed values to these two attributes is difficult to defend, the method used in this study is to detect the acceptable level of countermeasure effectiveness for each FRIFOR candidate. For each of the 42 encounters, another set of graphs, similar to previous ones, has been generated. While the Y-axis continues to show the number of remaining units and the FER, the X-axis now shows Countermeasure Effectiveness. To make the modeling easier, seduction and distraction values are inputted as equal values.

In the Salvo Equations, seduction countermeasure has a direct effect on the combat power of the opponent; distraction countermeasure has a direct effect on the fighting power of the opponent, which is a sub-part of combat power. Thus, both countermeasure values affect the enemy and, if kept at one, they have no effect. To reiterate the example in their definition, if seduction or distraction countermeasure is 0.85, 15% of enemy's missiles are seduced or distracted, respectively. In this section, seduction and distraction both take an equal value, forming the X-axis as Countermeasure Effectiveness between 0% and 50%. The number of OPFOR is fixed as before. To visually

investigate the graphs and detect the number of required ships for Breakpoint and Dominance, this time the number of FRIFOR ships is inputted manually.

Amongst the Iranian Naval Forces, the only vessels that could have countermeasure features are the Kilo class submarines and Kaman class PGFGs. The rest of the ships either have no significant features or there is no information about them. Kilo has torpedo countermeasures and Kaman has ESM/ECM equipment. They are not, however, competitive enough for FRIFOR. If included in the Salvo Equations, Iranian countermeasure effectiveness values would make insignificant improvements. Therefore, Iranian assets' countermeasure effectiveness is assumed one and has zero effect in the equations.

The acceptable level of countermeasures for each class is an assumption, basically a determined threshold, which is explained here. FRIFOR ships, except for Visby, can have the following maximum countermeasure effectiveness limits: 20% against submarines; 30% against PTFs; and 35% against PGFGs and PTGs. Counter-targeting against submarines is extremely hard. This is due to their covertness and is yet to be perfected. Therefore, this threat is the hardest to tackle. Although PTFs are surface vessels, if fired before distracted, a torpedo (as opposed to a missile) is harder to seduce, making PTFs the second deadliest threat in this scenario as seen in the base case results. Freedom's countermeasure effectiveness is assumed equivalent to the remaining four designs.

Visby, on the other hand, has significantly better design features. Many experts recognize it as one of the

few fully stealth and low-signature ships operational around the world. Since Visby is significantly smaller than the other candidates and to make the study more useful, it is conjectured that Visby has 10% more countermeasure effectiveness against OPFOR: 30% against submarines; 40% against PTFs; and 45% against PGFGs and PTGs.

Figures 5 and 6 visually display the effect of countermeasure on designs. A continuation of Figure 3, Visby versus 10 Thondor-PTG, Figure 5 shows the breakpoint requirement and Figure 6 shows the Dominance requirement. Force A is FRIFOR, Visby, and Force B is OPFOR, a combination of Thondor-PTG TG in TF 490. In Figure 5, the number of Visbys for this case is four. The X-axis is the countermeasure effectiveness, where value 0.0 represents 0% or no effect on countermeasure and 0.5 represents 50% effectiveness. This means that 50% of incoming successful enemy weapons are seduced or distracted. It is seen that at point 0.375 on X-axis, the FER goes over one and the number of remaining FRIFOR units becomes greater than remaining OPFOR. This point means that if the number of FRIFOR units is four, 38% countermeasure effectiveness, which is within the limit of 45% against PGFGs and PTGs, is enough to have a Breakpoint with OPFOR. More specifically, starting from one available FRIFOR ship, the number has been increased and its associated graph has been investigated. At four ships, it is seen that Breakpoint conditions are met at the 38% mark within the 45% countermeasure effectiveness limit. Thus, when countermeasure effectiveness is introduced to the equations, the number of required Visbys to have a Breakpoint with ten OPFOR ships drops from seven to four.

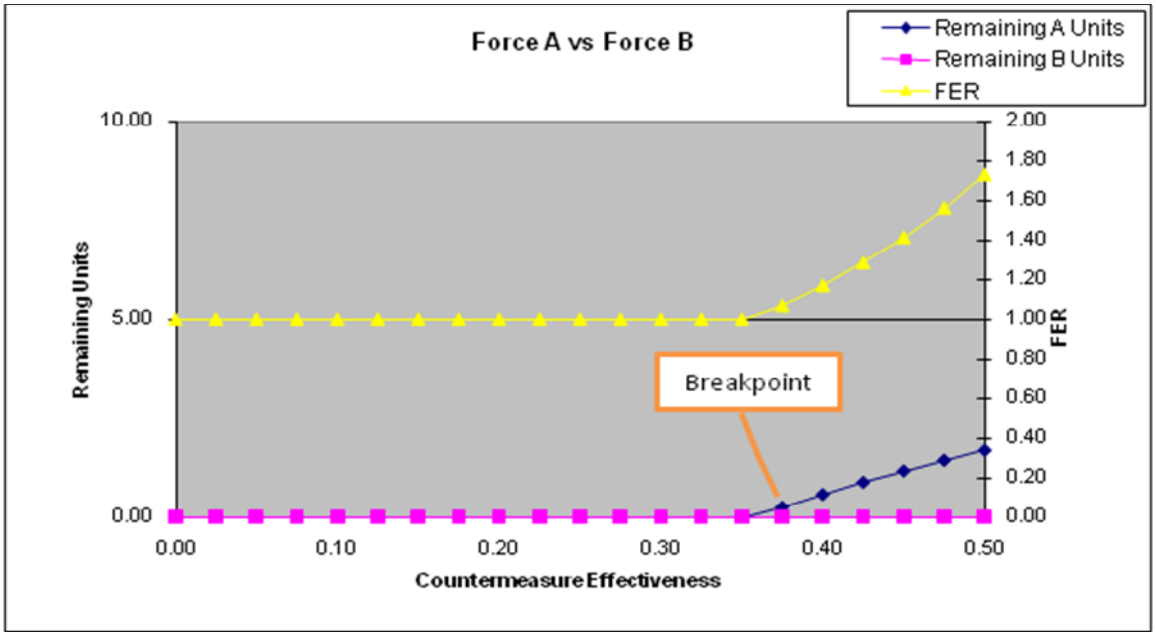

Figure 5. Visby vs. 10 x Thondor-PTG with Countermeasure Effectiveness, Breakpoint.

Figure 6 is the Dominance example of the same encounter. In this case, the number of available FRIFOR ships has been increased until Dominance conditions are met within the 45% limit. At seven Visbys present, it is seen that as the countermeasure effectiveness is increased, the number of remaining FRIFOR ships increase and reach the maximum, or the level of minimum losses due to leakers, at point 0.35, which is 35% effectiveness. From here on, Dominance conditions are met and seven Visbys is a big improvement from the previous result of 11. The important difference in this graph from the previous Dominance graph is that since X-axis is not the number of ships, but countermeasure effectiveness, after the Dominance point is reached, FER becomes a fixed number. After a certain level of effectiveness is provided, adding more does not change the result, since the enemy is already annihilated.

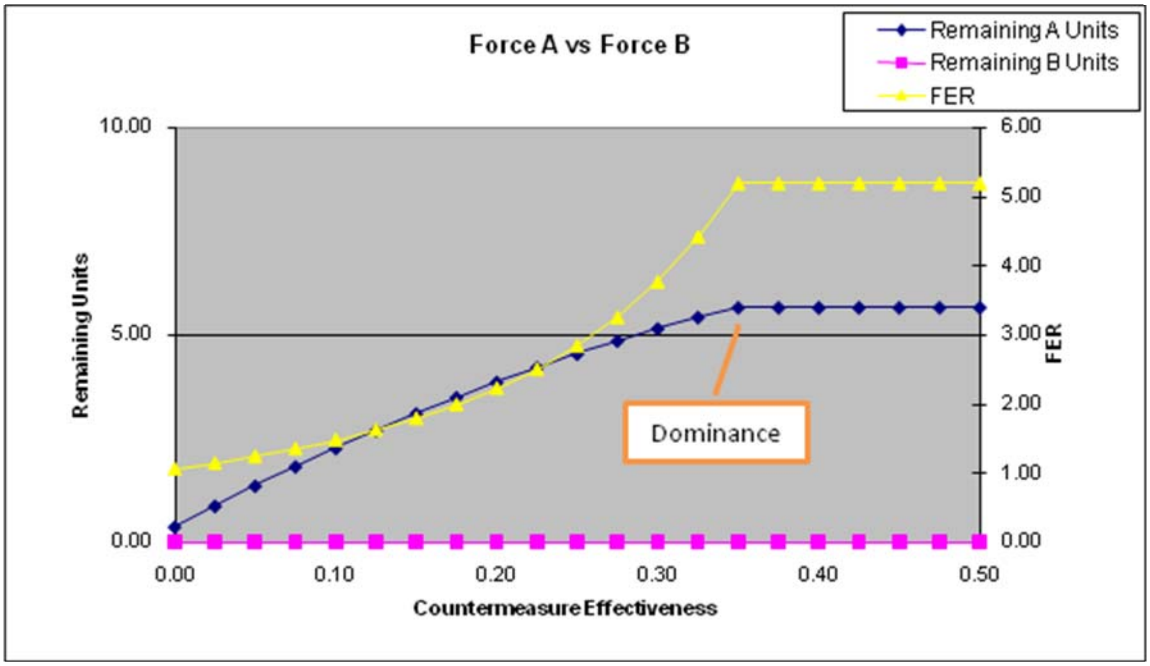

Figure 6. Visby vs. 10 x Thondor-PTG with Countermeasure Effectiveness, Dominance.

As a result, the 42 encounters have been reexamined with the addition of countermeasure effectiveness to FRIFOR. The number of available FRIFOR ships for each encounter is varied. Breakpoint and Dominance conditions, given the maximum countermeasure effectiveness limit for each candidate and encounter, are determined. The number of FRIFOR ships required for Breakpoint and Dominance is detected and shown in Table 21.

OPFOR	FRIFOR											
	Freedom		Formid.		MILGEM		Stere.		Sigma		Visby	
	Br.	Do.	Br.	Do.	Br.	Do.	Br.	Do.	Br.	Do.	Br.	Do.
TF 480												
2 x Kilo	4	5	4	5	4	5	4	5	4	5	3	4
5 x Kaman	3	3	3	3	3	3	3	3	5	6	3	4
3 x Yono	2	2	2	3	2	3	2	3	2	3	2	2
8 x PTG	2	2	3	3	3	3	3	3	5	6	5	6
9 x PTF	3	3	3	4	3	4	3	4	5	6	6	6
TF 490												
10 x Thondor-PTG	2	2	3	3	3	3	4	5	4	5	4	6
5 x PTF	2	2	2	2	2	2	2	2	3	4	3	4

Table 21. Breakpoint and Dominance Requirements with Countermeasure Effectiveness Approximation.

After including the countermeasure effectiveness, Table 22 shows the total required number of ships for Dominance.

OPFOR	FRIFOR					
	Freedom	Formidable	MILGEM	Steregushchiy	Sigma	Visby
TF 480	7	8	8	8	10	10
TF 490	3	3	3	5	5	6
TOTAL	10	11	11	13	15	16

Table 22. Total Number of Ships Required for Dominance with Countermeasure Effectiveness Approximation.

Without regard for cost, the final ranking of the FRIFOR candidates with countermeasure effectiveness as a real-time approximation is displayed in Table 23. The results for the base case, without the acknowledgement of countermeasure effectiveness, are written in parenthesis.

Ranking	Class	Number of Required Ships
1	Freedom	10 (13)
2	Formidable	11 (13)
3	MILGEM	11 (13)
4	Steregushchiy	13 (14)
5	Sigma	15 (18)
6	Visby	16 (22)

Table 23. FRIFOR Candidate Ship Ranking after Countermeasure Effectiveness Approximation.

G. SENSITIVITY ANALYSIS

Since the candidates are closely grouped together, it is important to note that Sensitivity Analysis is only as good as the input values. Regardless, Sensitivity Analysis is designed to enhance the understanding of the model's results. This section addresses the insights about the results of the encounters and how they compare amongst the FRIFOR candidates. The effects of hardkill boost on the initial base case results are also discussed. Not all encounters, however, are analyzed. Only the encounters where there is a significant difference amongst the candidates are analyzed.

1. FRIFOR vs. Submarine Encounters

In the base case, all submarine (Kilo and Yono) encounters by the FRIFOR candidates yield the same results. Against Kilo, four and six ships are required for Breakpoint and Dominance, respectively. The results are two and three for the Yono threat. Against Kilo, the reason for these results is that FRIFOR ships have the same defensive and staying power. The major contributor in this encounter is the defensive power. All FRIFOR ships have a defensive power of two. This is due to their lack of anti-torpedo weapons; therefore, they all perform poorly. Increasing this value has a major effect on the FER. For example, if it is four, then only three ships are required for Dominance against Kilo as opposed to the initial six.

Staying power has an effect as well, but not nearly as much as the defensive power. FRIFOR ships' different striking powers have no effect. This is because the defensive power is so low. Since it contributes to striking power, it is also found that targeting effectiveness has no effect as well. Defensive readiness, however, has some effect due to its contribution to defensive power. Freedom's defensive readiness is slightly better than others, but not enough to make a change on the integer results. Thus, Freedom performs slightly better than the others, while the others have the same performance regardless of their different striking powers. In the Yono engagement, since Yono's striking power is only two, the striking powers of FRIFOR ships do make some differences, but not enough to change the integer results. In conclusion, the reason that all anti-submarine results are

the same is because all ships have the same defensive power. This is found as the greatest contributor to FER.

2. FRIFOR vs. Kaman Encounters

The base case model run results for Breakpoint and Dominance show that, against five Kamans, they are the same as for the bigger candidates, three and three, respectively. The results are, however, significantly poorer for Sigma and Visby, five and six, respectively. Freedom and Steregushchiy perform slightly better than Formidable and MILGEM, due to the Hellfires and better attributes, but not enough to change their results. Sigma and Visby perform poorly. The reason that Sigma has poor results is her low striking power, four, which is the same as that of Kaman. The reason for Visby’s performance is low defensive power, which is two due to a lack of defensive missiles. These two disadvantages yield similar results for both ships. They are all worse than bigger ships. To improve performance, a hardkill boost is added to these two ships to bring them up to a similar level with the bigger ships, which will be discussed later.

Due to four Exocet SSMs on board, the striking power of Sigma is four. If this is increased to eight, the results for Breakpoint and Dominance would be three and four as opposed to five and six. This shows that for Sigma striking power is the greatest contributor to the FER. Defensive power and its contributor, defensive readiness, have no effect. This is due to discovering that its threshold for this encounter is three, which is Sigma’s defensive power. Staying power is found to have an insignificant effect. Targeting effectiveness, a

contributor to striking power, has an effect. In this encounter, however, it is not enough to change the results.

Since eight is found as the threshold (she has eight RBS SSMs), Visby's striking power has no effect. Visby's eight SSMs make her perform slightly better than Sigma. This is, however, not enough to change the results. Visby's greatest contributor to FER is her defensive power of two. It is lower than Sigma, prompting a hardkill boost by adding RAM. If defensive power is raised to the threshold of three, the results for Breakpoint and Dominance become four and four as opposed to five and six. Staying power has less effect than defensive power, but, since Visby is far smaller than the other candidates, it has a bigger effect than for Sigma. Since Visby's results are affected by defensive power, defensive readiness has an effect as well, but not enough to change the results. Finally, since striking power is at the threshold already, targeting effectiveness is found to have no effect.

3. FRIFOR vs. PTGs Encounters

In these FRIFOR encounters against eight PTGs, the results pose similar questions and answers to those of Kaman encounters. If results are revisited, Freedom encounter requires two ships for both Breakpoint and Dominance. The other bigger ships require three for both. Sigma encounter requires five ships and six ships and Visby requires six and eight. Freedom's better performance is a result of her ability to employ two ASUW helicopters with 16 Hellfires; the others only employ a single helicopter. Sigma and Visby both employ the lighter version of Seahawk, which can carry only four Hellfires. Therefore, a striking

power of four yields poorer results. The reason that Visby performs even poorer than Sigma is due to her lower defensive power of two, which results in two more ships being needed than for Sigma. This is a major effect on the FER. Since striking power is low, targeting effectiveness has some effect on both ships, but not enough to change the results. Defensive readiness for Visby has a bigger effect than Sigma. This is because Visby truly suffers from low defensive power. When defensive readiness is improved to one, the result is also improved by requiring one less ship. Staying power is similar to Kaman encounters and has little effect.

4. FRIFOR vs. PTFs Encounters

In the center and western entrances of the Strait of Hormuz, where FRIFOR battles against the attacker waves of nine and five PTFs, respectively, the results for Breakpoint and Dominance provide similar insights. Against nine PTFs, Freedom performs slightly better than other bigger ships due to her two helicopters. All larger ships perform better than Sigma and Visby. The outcome trend is the same against five PTFs.

This better performance is only one less required ship and that is due to the lower striking power of Sigma and Visby. The striking power of FRIFOR ships is the same as against PTGs and their defensive power is three against torpedoes coming from PTFs. These ships do not have defensive weapons against torpedoes, but are able to maneuver early due to detecting the surface launch. This gives them better defensive power than against submarines. Staying power has little effect, however, between Sigma and

Visby. Staying power is the reason why Sigma requires one less ship for Breakpoint against nine PTFs. Against a smaller group, one with five PTFs, staying power is no longer an advantage for Sigma and the integer results are the same as for Visby. Targeting effectiveness and defensive readiness explanations are the same as against PTGs.

5. FRIFOR vs. Thondor-PTGs Encounters

This encounter is most challenging for FRIFOR. The scenario is created to understand the impact of TF 490 changing tactics by uniting its PGFG and PTG attacker waves to swarm the FRIFOR in the western entrance of the Strait. This combined TG of ten PGFGs and PTGs fire only C-802s and C-701s, while FRIFOR units respond and attack with all they have (helicopters and ships) regardless of target-weapon ratio policies. In this case, the striking power of all FRIFOR candidates is higher than in previous encounters. Freedom has 16 Hellfires from two ASUW helicopters; Formidable and MILGEM also have 16, but that counts shipboard and helicopter missile combined. Steregushchiy has only eight Hellfires available. This is because there are no SSMs onboard. Sigma has eight missiles from both SSMs and Hellfires (four of each), while Visby has the same situation but with eight SSMs, giving her a total of 12 missiles with her four airborne Hellfires.

The results are predicted to be high numbers of required FRIFOR ships; however, this does not match the actual outcome. As a result of high striking power, Freedom requires only two and three ships for Breakpoint and Dominance, respectively, against 10 swarming OPFOR ships.

MILGEM and Formidable have results similar to those of Freedom. One more ship, however, is required for Breakpoint. This is due to Freedom’s better attributes, such as defensive readiness. This attribute stands out as having more effect than the others and creates the one-ship difference. Formidable and MILGEM have the same integer results, three and three, although Formidable performs slightly better. Steregushchiy has a striking power of eight and the results for her are four and five. For this engagement, striking power is the major contributor for FER. When increased to those of bigger ships, the same results are achieved. Defensive power and readiness does not have enough effect to change the results for Steregushchiy. Targeting effectiveness, however, when improved, makes an impact to the result with one less ship required.

Sigma and Visby both have low defensive power and this is the main reason for their poor performance. For Breakpoint and Dominance, Sigma requires five and eight ships; while Visby requires seven and eleven. Due to these poor results, especially for Visby, hardkill boost was considered as a special case. Improving striking power for these ships has no significant effect on FER. This shows that, if both sides are similar to each other in terms of attributes, the one with better defensive power dominates. When Sigma’s defensive power is increased from three to five, the result is three fewer ships for Dominance. Even better than Sigma, when Visby’s defensive power is increased from two to three, the result improves with three fewer ships. These improvements of slight increase in defensive power show that defensive power is the critical

contributor to the FER. It is also discovered that increasing defensive readiness has some effect, while the remaining attributes have no impact on results. Finally, staying power for FRIFOR candidates is found to have an insignificant effect. This is because the equations for the smaller ships are deeply affected by lower defensive and striking powers than the bigger ships.

6. Hardkill Capability Boost to Sigma and Visby

Increasing hardkill defensive capability through addition of a RAM launcher to Sigma and Visby has been previously addressed. The results indicated that increasing defensive power to make it similar to that of bigger ships pays off, especially for Visby, which had a very low defensive power of two. Granted this hardkill defensive measure effects only three types of encounters out of seven, Sigma has better Breakpoint and Dominance results only against the swarming Thondor-PTGs combined TG. Previous results for Sigma were five and eight. After the capability boost, they improved to four and five. On the other hand, Visby has significantly improved against all three threats. The reasons for these non-improvements and improvements have been explained earlier. It is, however, essential to reiterate.

Even with the addition of RAM and bringing the defensive power to eight, the reason for Sigma’s non-improvement against Kamans and PTGs is caused by the lack of enough striking power. If striking power is increased to the levels of others and a slight improvement is made in defensive power, the same results could be achieved. Against Thondor-PTGs, the results improved with RAM

addition, but not by as much as in the other cases. In this case, increasing defensive power made an effect. This is because striking power was higher than before. Therefore, the striking power of Sigma is the greatest contributor to the FER, whereas defensive power is only secondary in importance.

Visby differs from Sigma, as Visby improved tremendously with a defensive weapon addition. Against Kamans, the Dominance result is three fewer ships; against PTGs, two fewer ships, and against the Thondor-PTGs swarm, a large improvement from eleven ships to three ships resulted. Against Kamans, Visby has enough striking power, but almost no defensive power, resulting in poor performance. When RAM is added, the results are the same as for the bigger ships. Against PTGs, the RAM enhanced Visby improves by requiring two fewer ships. However, since she does not have enough striking power, she cannot compete with the larger ship alternatives. Even in these environments, however, defensive power is a must. Finally, against ten swarming ships, the results for Breakpoint and Dominance drop from seven and eleven to three and three. This is similar to the Kaman encounter where there is enough striking power, but almost no defensive power. Therefore, given striking power is present, all Visby needs to get to the performance level of bigger ships is enhanced defensive power. In summation, Visby’s defensive power has utmost importance for the FER, while striking power is of second degree importance.

H. HARDKILL CAPABILITY BOOST REVISITED

The base case results showed that a hardkill capability of a RAM launcher is necessary for Sigma and Visby to boost their defensive power to those of the bigger ships. In order to explore further enhancements to these ships for creating a powerful yet less expensive alternative than the larger ships is now addressed. Sigma's main contributor to FER is striking power; the main contributor for Visby is defensive power. In addition to the initial RAM launcher boost, to bring these two designs up to the level of the other candidates the following capabilities are considered for enhancing their capabilities.

Sigma normally carries a quad Exocet SSM launcher. If upgraded to an octuple launcher, it will match most modern frigates and corvettes. Visby already has an octuple RBS SSM launcher. Thus, they become equally offensive. Against PTGs and PTFs, however, all FRIFOR ships, due to weapon-target proportionality reasons, use their helicopters and the air-launched Hellfires. Since their size is an issue, Visby and Sigma employed a lighter version of Seahawk which can carry only four Hellfires or two Mk-54 torpedoes in the base case. Sigma and Visby are enhanced to employ MH-60R Seahawk, which can carry eight Hellfires and four MK-54 torpedoes; it doubles their offensive power. A major assumption is that Visby receives the necessary deck modifications to receive a heavier helicopter.

As seen in the Sensitivity Analysis section, having additional torpedoes has an insignificant effect against submarines. This is because striking power is not a

contributor to FER due to very low defensive power. Having eight Hellfires, however, will have direct effect against PTGs and PTFs. FRIFOR ships are to use SSMs against the PGFGs. Against the swarming attack of Thondor-PTGs, however, having four extra Hellfires will contribute to the FER. This is because FRIFOR is to use the combined power of ship and helicopter.

When all these improvements are provided to Sigma and Visby, the results for Breakpoint and Dominance ship requirements are displayed in Table 24. Submarine encounters are omitted, since there is no change in these encounters.

OPFOR	FRIFOR							
	Sigma Before HK		Sigma After HK		Visby Before HK		Visby After HK	
	Br.	Do.	Br.	Do.	Br.	Do.	Br.	Do.
TF 480								
5 x Kaman	5	6	**3**	**3**	5	6	**3**	**3**
8 x PTG	5	6	**3**	**3**	6	8	**3**	**3**
9 x PTF	5	6	**4**	**5**	6	6	**4**	**5**
TF 490								
10 x Thondor-PTG	5	8	**3**	**3**	7	11	**3**	**3**
5 x PTF	3	4	**2**	**3**	3	4	**3**	**3**

Table 24. Breakpoint and Dominance Requirements with Revised Hardkill Capability Boost to Sigma and Visby.

As can be seen, Sigma and Visby have now come to the level of other candidates. One minor point is that Visby requires one more ship for Breakpoint against five PTFs, since her lower staying power against torpedoes. After this hardkill boost, the changes in the total required number of ships for Dominance are shown in Table 25.

OPFOR	FRIFOR			
	Sigma Before HK	Sigma After HK	Visby Before HK	Visby After HK
TF 480	10	**9**	11	**9**
TF 490	8	**4**	11	**4**
TOTAL	18	**13**	22	**13**

Table 25. Total Number of Ships Required for Dominance after Revised Hardkill Boost to Sigma and Visby.

With enhanced Sigma and Visby, the ranking changes as in Table 26. The required number of ships for Sigma and Visby without the hardkill boost is written in parenthesis.

Ranking	Class	Number of Required Ships
1	Freedom	13
2	Formidable	13
3	MILGEM	13
4	Sigma	13 (18)
5	Visby	13 (22)
6	Steregushchiy	14

Table 26. FRIFOR Candidate Ship Ranking after Revised Hardkill Boost to Sigma and Visby.

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V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

This thesis is the applied art of a tactical situation using a mathematical method. The results generated are necessary insights for operational planning. An evaluation and comparison of FRIFOR candidates have been conducted. Based on an Iranian OPFOR scenario the results yield the conclusions summarized in this section.

A major conclusion is that helicopters, especially the two on LCS, have a crucial impact on the results. Helicopters are an essential organic asset of a surface ship. With a powerful, capable and lethal helicopter, multi-axis threats can be addressed, given no SAM threat to the helicopters. Another major conclusion is that it is hard to prevent losses. Therefore, effectively attacking the enemy first is a priority. This is especially true when operating in an enemy’s littoral. Overwhelming the enemy with striking power while sustaining a credible defense is key to success with minimum acceptable losses.

1. Results

The base case results, without any hardkill boost or consideration of countermeasure effectiveness, indicate the first trend amongst the candidates. The number of ships required from each FRIFOR candidate for Dominance against the specified OPFOR threat in the base case is shown in the performance rankings of Table 27. The numbers in parentheses represent the number of required ships for Dominance against the attacker OPFOR. The second number in

parentheses is the value against two Yono class submarines and five PTFs in the Submarines and PTFs columns, respectively.

Rank	Against OPFOR				
	Submarines	PGFGs	PTGs	PTFs	PGFGs-PTGs
1	Freedom (6,3)	Freedom (3)	Freedom (2)	Freedom (5,3)	Freedom (3)
2	Formidable (6,3)	Steregush. (3)	Formidable (3)	Formidable (5,3)	Formidable (3)
3	Steregush. (6,3)	Formidable (3)	Steregush. (3)	Steregush. (5,3)	MILGEM (3)
4	MILGEM (6,3)	MILGEM (3)	MILGEM (3)	MILGEM (5,3)	Steregush. (5)
5	Sigma (6,3)	Visby (6)	Sigma (6)	Sigma (6,4)	Sigma (8)
6	Visby (6,3)	Sigma (6)	Visby (8)	Visby (6,4)	Visby (11)

Table 27. Base Case Performance Rankings.

When the countermeasure effectiveness attributes of the FRIFOR ships are accounted for as real-time approximations in the Salvo Equations Model, the above results improve as depicted in Table 28.

Rank	Against OPFOR				
	Submarines	PGFGs	PTGs	PTFs	PGFGs-PTGs
1	Visby (4,2)	Freedom (3)	Freedom (2)	Freedom (3,2)	Freedom (2)
2	Freedom (5,2)	Steregush. (3)	Formidable (3)	Formidable (4,2)	Formidable (3)
3	Formidable (5,3)	Formidable (3)	Steregush. (3)	Steregush. (4,2)	MILGEM (3)
4	Steregush. (5,3)	MILGEM (3)	MILGEM (3)	MILGEM (4,2)	Steregush. (5)
5	MILGEM (5,3)	Visby (4)	Sigma (6)	Sigma (6,4)	Sigma (5)
6	Sigma (5,3)	Sigma (6)	Visby (6)	Visby (6,4)	Visby (6)

Table 28. Performance Rankings with Countermeasure Effectiveness.

Table 29 shows the improvements of the results for Sigma and Visby with the addition of hardkill capability, initially and after a revision. Hardkill boost does not affect the submarine encounters, and only the revised hardkill boost affects the PTF encounters.

Rank	Against OPFOR						
	PGFGs		PTGs		PTFs	PGFGs-PTGs	
	Initial HK Boost	Revised HK Boost	Initial HK Boost	Revised HK Boost	Revised HK Boost	Initial HK Boost	Revised HK Boost
1	Freedom (3)	Freedom (3)	Freedom (2)	Freedom (2)	Freedom (5,3)	Freedom (3)	Freedom (3)
2	Stere. (3)	Stere. (3)	Formid. (3)	Formid. (3)	Formid. (5,3)	Formid. (3)	Formid. (3)
3	Formid. (3)	Formid. (3)	Stere. (3)	Stere. (3)	Stere. (5,3)	MILGEM (3)	MILGEM (3)
4	MILGEM (3)	MILGEM (3)	MILGEM (3)	MILGEM (3)	MILGEM (5,3)	Visby (3)	Sigma (3)
5	Visby (3)	Sigma (3)	Sigma (6)	Sigma (3)	Sigma (5,3)	Stere. (5)	Visby (3)
6	Sigma (6)	Visby (3)	Visby (6)	Visby (3)	Visby (5,3)	Sigma (5)	Stere (5)

Table 29. Performance Rankings after Initial and Revised Hardkill Boost to Sigma and Visby.

Finally Table 30 shows the side-by-side rankings of the FRIFOR candidates along with the total number of ships for base case and the special cases above.

Rank	Base Case		With Countermeasure Effectiveness		Initial Hardkill Boost		Revised Hardkill Boost	
	Class	# of Ships	Class	# of Ships	Class	# of Ships	Class	# of Ships
1	Freedom	13	Freedom	10	Freedom	13	Freedom	13
2	Formid.	13	Formid.	11	Formid.	13	Formid.	13
3	MILGEM	13	MILGEM	11	MILGEM	13	MILGEM	13
4	Stere.	14	Stere.	13	Stere.	14	Sigma	13
5	Sigma	18	Sigma	15	Visby	15	Visby	13
6	Visby	22	Visby	16	Sigma	15	Stere.	14

Table 30. Aggregate Rankings of FRIFOR Candidate Ships.

2. Modeling Submarine Encounters in Salvo Equations

Use of Salvo Equations for a submarine versus surface ship encounter has not previously been investigated in detail. What has been done in this thesis is a crude first approximation representation of this encounter for the purpose of exploring the suitability of Salvo Equations. Perhaps modeling ASW is an excessive stretch of the model, but seemingly it is a successful experiment with useful insights. One of the reasons for modeling this encounter is to increase the number of threats in realistic scenarios. The main reason, however, is to see what insights can be had by using Salvo Equations for the ship-on-submarine battles. The result found most insightful is that two conventional Kilo class submarines require six surface vessels for domination. This is due to lack of torpedo

defensive weapons. This large ship requirement argues for the necessity that before any littoral operation, clearing the submarine threat must be a high priority, before moving in to encounter the swarming PGFGs or small boats. Employing dedicated ASW surface and air assets are the best fit for the job.

3. How Much Countermeasure Effectiveness is Enough?

The answer to this question can never be found with high confidence. It should be emphasized that very few studies have adequately looked at counter-targeting and softkill. In this thesis, this important issue has been addressed and investigated. By parameterizing countermeasure effectiveness, this study demonstrates that countermeasure effectiveness is important, but how much of it is to be attained before an engagement is problematic because there is no way to assuredly quantify countermeasures effectiveness in an engagement. For each encounter by each FRIFOR candidate, the model displays the effect of the countermeasure effectiveness to the FER by changing the number of FRIFOR ships required for Dominance. Each FRIFOR ship has her limitations; therefore, an acceptable level of countermeasure has been determined for each encounter. This method is seen as the best way of approaching the question above: not quantifying the countermeasure attributes of the ships, but determining the integer number of required ships for Dominance in each encounter. Each FRIFOR ship’s countermeasure attributes have been evaluated using this technique and a real-time approximation of the scenario using the model has been achieved.

4. Freedom Class LCS

The aggregate results indicate that Freedom class LCS is the best performer in almost all cases against the OPFOR within this scenario, although the larger alternatives have either close or the same integer results. Including the countermeasure effectiveness for a better real-time approximation of Hughes' Salvo Model, it could be deduced that a total of ten LCSs (seven situated in the center and three in the western entrance of the Strait of Hormuz) can dominate the Iranian threat as described in this OPFOR scenario. This finding concurs with Abbott's thesis results (2008), which suggested 6-10 LCS to be employed against a multi-axis threat, using a different analytical tool to explore the similar encounters.

Lack of SSMs and ship-launched torpedoes do not hinder Freedom, given both helicopters are ready on the ship for tasking. When both helicopters are in the air, Freedom's firepower is doubled, giving her an advantage to overwhelm the enemy. Furthermore, employing Hellfires against small combatants is proven effective, since WHP and Leakage Rate of this missile are assumed higher than Harpoon's. Unless the enemy operates a SAM or PDMS firing ship, employing Hellfires from helicopters is the best option. The stand-off distance of enemy's AAW gun firing boats is insignificant for Hellfire firing range.

In addition to her double helicopter capability and enhanced firepower, Freedom's UAV capability, high speed and better signature features give her a clear advantage over the other FRIFOR candidates. Freedom's RAM PDMS, when enhanced with the 57 mm rapid firing AAW gun, shows that a

SAM capability is not necessary. In addition to sufficient defensive power, staying power is also shown to be sufficient. Procurement cost, however, is an important consideration. Although the cost of LCS is introduced as $400 million, based on open-source literature, it may be more expensive, i.e., $500 million.

5. Formidable Class Frigate and MILGEM Class Corvette

Formidable and MILGEM are the designs that perform almost equal to each other. There are slightly better results on Formidable’s side. Both are also close to Freedom’s performance. With just one more ship required in the center of the Strait against TF 490, a total of 11 ships are required for Formidable or MILGEM to accomplish the mission with countermeasure effectiveness included. Since Formidable is a traditional modern frigate and MILGEM is a modern corvette, their close performance was anticipated. Formidable is just a bigger-sized version of MILGEM with similar weapons (except for Formidable’s SAM capability as opposed to MILGEM’s RAM). But as to model values, this difference has a slight impact. Other than the size difference, which affects the staying power, there is almost no difference between Formidable and MILGEM in terms of Salvo Equation attributes. Similar to Freedom’s real cost prediction, Formidable’s approximate cost is $400 million and MILGEM’s cost is $300 million.

6. Steregushchiy Class Frigate

Steregushchiy was not considered a strong candidate. However she has proven sufficient and overall yielded results just below the three ships already mentioned. In

the base case, 14 Steregushchiy ships are required for the scenario, which is just one below the requirements for the three ships above. With countermeasure effectiveness involved in the equations, eight ships in the center and five ships in the western entrance of the Strait, a total of 13 ships are enough to dominate the OPFOR. The main reason to require two more ships than Formidable or MILGEM is that Steregushchiy, similar to Freedom, lacks SSMs, and has no additional helicopters or air assets. Thus, against the swarming attack of Thondors and PTGs in the western part of the Strait, Steregushchiy lacks firepower to respond to the overwhelming number of attackers. She requires two more ships here. Elsewhere, she yields the same results as Formidable and MILGEM. Interesting, Steregushchiy performs slightly better than MILGEM in many cases, but the results, since they are integers, do not change. For a real-time cost approximation of this Russian ship, $250 million is assumed to be a safe number for comparison.

7. Sigma Class Corvette

As anticipated, a smaller candidate without a hangar and limited helicopter capability, Sigma performed relatively poorer than the bigger candidates. The analysis shows that her lack of a robust defensive capability, as well as the smaller number of offensive missiles, yielded worse results. For the base case, 18 ships are required for the mission. When her defensive capability is boosted to the levels of bigger ships, however, a total of 15 ships are needed, matching the result with just the countermeasure effectiveness. With an additional hardkill

boost, this number drops down to 13 ships, which is same as the bigger ships. Thus, it is shown that adding hardkill boost yields better results: from 18 ships down to 13 ships.

The addition of RAM in place of a less effective PDMS, increasing Exocet numbers from four to eight and upgrading the helicopter to a full version of Seahawk with eight Hellfires make Sigma as competitive as the bigger candidates. Sigma performs better than Visby in the base case. When other cases are considered, the results are almost the same or slightly in favor of Sigma. This is mainly due to Sigma being more than twice the size of Visby. The main point is that a cheaper and smaller asset with the right weapons mix can be as effective as the bigger and more expensive ships. Adding hardkill measures to Sigma affects her combat attributes in this study. For modeling purposes, however, this effect is omitted. As previously reported the unit cost of Sigma is considered to be around $200 million and seems a reliable estimate.

8. Visby Class Corvette

This ship is chosen to compare bigger ships with a smaller one in this scenario, specifically Freedom versus Visby. Although predicted competitive, the base case results indicate otherwise. However, when countermeasure effectiveness is included, the results improve from 22 down to 16 ships. When additional hardkill is also provided, the result is the same as for the other candidates. This is just like Sigma’s case and better than Steregushchiy. Although Visby has torpedoes and eight RBS SSMs, the fact that there is no defensive SAM or PDMS capability is her

main limitation for the base case. As this attribute is improved by adding RAM PDMS, the result changes from 22 to 15. Furthermore, when the helicopter size is upgraded to a full version, the result becomes 13. Visby is certainly a competitive ship and, with minor changes, becomes equal to the bigger ships. What makes it competitive is not the effective weapons, but the proportionate size and power. Visby’s previously reported cost is $200 million and is not likely to change, regardless of the assumptions made in the introduction of a hardkill capability. Given her small size and low cost, she becomes the most suitable FRIFOR asset for this mission. She is also favored over Sigma due to lower operational costs.

B. RECOMMENDATIONS

In this final section, the cost and the optimum design features of the evaluation of the FRIFOR designs are incorporated. Future study suggestions are also made.

1. Cost

The cost of each FRIFOR candidate has been addressed in the previous section. Table 31 displays the cost comparison of this scenario for each FRIFOR candidate with the countermeasure effectiveness included and the revised hardkill boost added to Sigma and Visby. Base case and initial hardkill boost costs are omitted. Hardkill boost to Sigma and Visby is assumed not to affect the cost of these ships.

Rank	With Countermeasure Effectiveness			Revised Hardkill Boost		
	Class	# of Ships	Cost (millions)	Class	# of Ships	Cost (millions)
1	Sigma	15	15 x 200 = $3000	Sigma	13	13 x 200 = $2600
2	Visby	16	16 x 200 = $3200	Visby	13	13 x 200 = $2600
3	Stere.	13	13 x 250 = $3250	Stere.	14	14 x 250 = $3500
4	MILGEM	11	11 x 300 = $3300	MILGEM	13	13 x 300 = $3900
5	Formid.	11	11 x 400 = $4400	Formid.	13	13 x 400 = $5200
6	Freedom	10	10 x 500 = $5000	Freedom	13	13 x 500 = $6500

Table 31. Cost comparison of FRIFOR Candidates.

Without considering the hardkill boost, simply applying the countermeasure effectiveness, which is already built in the ships, the results indicate that the first four candidates are clearly cheaper to acquire for the mission in the Strait of Hormuz. With the introduction of hardkill boost to Sigma and Visby, without even accounting for the countermeasure effectiveness, the first two candidates, Sigma and Visby, are clearly the optimum choices for acquisition. The main recommendation is the acquisition of cheaper assets. Although it requires more

numbers to buy for the mission accomplishment, the overall cost is cheaper. Another conclusion is that the medium sized ships, Steregushchiy or MILGEM, are also options for a small increase in the overall cost. This satisfies the big picture concerns, such as stand-alone sustainment, longer on-station times and less susceptibility to higher sea states.

It is clear that Freedom is the best performer. Her high procurement cost, however, makes her the least cost-effective candidate. Formidable and MILGEM, performing almost the same, have a major gap in unit procurement cost. This, therefore, makes Formidable not as cost-effective. The overall requirement for MILGEM is less than Steregushchiy. The cost difference, however, also makes Steregushchiy an alternative to MILGEM. Hence, for a medium size, the more cost-effective candidates are MILGEM and Steregushchiy. If the sustainment concerns are omitted, the best cost performers are Sigma and Visby. Sigma is more than twice the size of Visby making her a more sustainable candidate. Visby’s lower operational costs, as well as fast speed and stealth features make her a competitive option. In the end, this is a combat analysis and one has to take into consideration that bigger ships have more of a value for sustainment reasons. Therefore, medium size ships, such as MILGEM and Steregushchiy, look attractive due to increased sustainment, station time, and sea state endurance.

2. Optimum Design

For an optimum design consideration, in addition to an octuple SSM launcher, the best weapons mix is an AAW gun,

76 mm or 57 mm, with RAM PDMS. A full-size helicopter is also necessary to deliver Hellfires against swarming attackers. For operational fitness, if the ship has no hangar, then a mother ship for the helicopter should be considered for logistic support. If SSMs are not carried, then a double helicopter capability is a must. Since this requires a hangar, a bigger size ship is needed, which in turn increases the cost. If there is not a double helicopter capability, ship-launched torpedoes are also required.

An optimum design requires a balance between the three major attributes of the Salvo Equations: striking, defensive, and staying powers. Only with this balance, and a minimum cost, can an optimum design be foreshadowed. This optimum design best fits the MILGEM corvette. With her 76 mm gun, RAM, octuple Harpoon launcher, ship launched torpedoes, sufficient stealth features, and a hangar with a full size helicopter, MILGEM is the best fit for this mission with the lowest total procurement cost and highest overall effectiveness.

3. Future Study

The Salvo Equations Model is limited to some extent for enhanced warfare modeling. Different aspects of warfare cannot be easily modeled due to the mathematical nature of the model. A further study on this scenario with other analytical tools is recommended. This effort should add the omitted Iranian threats, such as shore-based mobile C-802 launchers and recently procured Chinese impact mines.

Along with the Hughes Salvo Equations Model, a simulation software tool and intelligent experimental

design may be used to visualize the scenario and further explore the value of ship attributes. MANA (Map Aware Non-Uniform Automata) is an agent-based distillation model, one of the common simulation and modeling tools used by military operation analysts. It was developed by New Zealand DTA (Defense Technology Agency). This model is very helpful in simulating behaviors of “agents”, e.g., ship and helicopter, and would provide great visual and statistical results for the given scenario. The aim of running a MANA model, using the same scenario, is to verify or challenge the results of the Hughes Salvo Equations Model using a different analytical approach.

Another visual tool to model the same scenario is the commercial game, Harpoon 3 Advanced Naval Warfare, by Matrix Publishing Company. A tactical scenario editor is built in to create a custom-made scenario. This can easily accommodate the Strait of Hormuz scenario and provide a visual realization of this study within a short period of time. Requiring no more skills than a strategy and simulation game player, the aim is to apply real-time scenarios to a game editor and quickly determine results for decision makers.

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APPENDIX A. FRIENDLY FORCE ASSETS

A. FREEDOM CLASS LCS FLIGHT 0

USS Freedom (LCS-1), built by Lockheed Martin in Marinette Marine, Wisconsin, was commissioned on 8 November 2008. USS Forth Worth (LCS-3) is due to be commissioned in 2013. A total of 55 LCSs is proposed.

Displacement	3089 tons, full load
Dimensions	115.3 m x 13.1 m x 3.9 m (Length, Beam, Draft)
Main Machinery	CODAG; 2 GT (96550 hp), 2 Diesels (17160 hp), 4 Waterjets
Speed, Range	45 Kts, 3500 NM at 18 Kts
Complement	50+25 mission package crew and aircrew
Missiles	1 RAM RIM-116, 21-cell Mk 99 launcher, Passive IR/anti-radiation homing to 5.2 NM at 2.5 Mach, Warhead 9.1 kg
Guns	1 57 mm/70 Mk 2, 220 rds/min to 9 NM, shell weight 2.4 kg, 4 12.7 mm MG
Countermeasures	2 SKWS/SRBOC decoy launcher, ESM/ECM
Helicopters	2 MH-60 R/S Helicopter or 1 MH-60 R/S and 3 MQ-8B Fire Scout VTUAVs
Notes	7 Mission Modules (3 MW, 2 ASW, and 2 ASUW) are to be used interchangeable on LCS. Capability to launch and recover manned and unmanned boats

Table 32. Freedom Class LCS Characteristics.

Figure 7. USS Freedom-1 (LCS-1), from JFS.

Figure 8. USS Freedom-2 (LCS-1), from JFS.

B. FORMIDABLE (PROJECT DELTA) CLASS FRIGATE (FFGH)

RSS Formidable (F-68), built by DCN, Lorient for Singapore Navy, was commissioned on 5 May 2007. Five more of the same class (F-69 through 73) have been built by Singapore SB and Marine, commissioned between 2008 and 2009.

Displacement	3200 tons, full load
Dimensions	114 m x 16 m x 5 m (Length, Beam, Draft)
Main Machinery	CODAD; 4 Diesels (48276 hp), 2 shafts, bow thruster
Speed, Range	27 Kts, 4000 NM at 15 Kts
Complement	71+15 aircrew
Missiles	SSM: 8 Harpoon, active radar homing to 70 NM at 0.9 Mach, Warhead 227 kg. SAM: 4 octuple Sylver VLS for MBDA Aster 15, command guidance active radar homing to 8.1 NM anti-missile, to 16.2 NM anti-aircraft, 32 missiles
Guns	1 76 mm/62, 120 rds/min to 8.7 NM, shell weight 6 kg, 2 20 mm MG, 2 12.7 mm MG
Torpedoes	6 324 mm tubes, A 244/S Mod 3, active/passive homing to 3.8 NM at 33 Kts, Warhead 34 kg
Countermeasures	3 NGDS 8-barrelled decoy launcher, ESM
Helicopters	1 S-70B Seahawk
Notes	Derived from La Fayette design. Two of the four VLS launcher can launch longer range Aster 30 SAM

Table 33. Formidable Class Frigate Characteristics.

Figure 9. RSS Formidable (F-68), from JFS.

Figure 10. RSS Tenacious (F-71), from JFS.

C. MILGEM CLASS CORVETTE (FSGH)

TCG Heybeliada (F-511), built by Istanbul Naval Shipyard for Turkish Navy, launched on 27 September 2008 and is due to be commissioned in 2011. TCG Buyukada (F-512) is to be commissioned in 2014. Six other ships are proposed.

Displacement	2000 tons, full load
Dimensions	99 m x 14.4 m x 3.6 m (Length, Beam, Draft)
Main Machinery	CODAG; 2 Diesels (11750 hp), 1 GT (20500 hp), 2 shafts
Speed, Range	29 Kts, 3500 NM at 15 Kts
Complement	93
Missiles	SSM: 8 Harpoon, active radar homing to 70 NM at 0.9 Mach, Warhead 227 kg. SAM: 1 RAM RIM-116, 21-cell Mk 49 launcher, Passive IR/anti-radiation homing to 5.2 NM at 2.5 Mach, Warhead 9.1 kg
Guns	1 76 mm/62, 120 rds/min to 8.7 NM, shell weight 6 kg, 2 12.7 mm MG
Torpedoes	4 324 mm tubes
Countermeasures	TBA, ESM/ECM
Helicopters	1 S-70B Seahawk
Notes	8 ASW and OPVs are proposed with a follow up of 4 slightly larger F-100 class frigates, the predecessors of TF-2000 (Turkish Frigate)

Table 34. MILGEM Class Corvette Characteristics.

Figure 11. TCG Heybeliada-1 (F-511), from JFS.

Figure 12. TCG Heybeliada-2 (F-511), from JFS.

D. STEREGUSHCHIY CLASS (PROJECT 20380) FRIGATE (FFGH)

RS Steregushchiy (F-530), built at Severnaya, St. Petersburg for Russian Navy, was commissioned on 14 November 2007. Four more of this design are being built and to be commissioned between 2010 and 2011. Two more are proposed.

Displacement	2200 tons, full load
Dimensions	104.5 m x 11.1 m x 3.7 m (Length, Beam, Draft)
Main Machinery	CODAD; 4 Diesels (24000 hp), 2 shafts
Speed, Range	26 Kts, 3500 NM at 14 Kts
Complement	100
Missiles	1 CADS-N-1 Kashtan, twin 30 mm Gatling combined with 8 SA-N-11 Grisson, laser beam guidance to 4.4 NM, warhead 9 kg, 9000 rds/min for guns
Guns	1 100 mm, 80 rds/min to 11.6 NM, shell weight 15.6 kg, 2 30 mm/65 AK 630 CIWS, 3000 rds/min, 2 14.5 mm MG
Torpedoes	8 324 mm tubes, anti-torpedo active/passive homing to 2.7 NM, warhead 70 kg
Countermeasures	4 PK 1- launchers, ESM/ECM
Helicopters	1 Ka-27 Helix
Notes	Space is provided for 8 SS-N-25 SSMs

Table 35. Steregushchiy Class Frigate Characteristics.

Figure 13. RS Steregushchiy-1 (F-530), from JFS.

Figure 14. RS Steregushchiy-2 (F-530), from JFS.

E. SIGMA CLASS CORVETTE (FSGH)

KRI Diponegoro (F-365), built at Royal Schelde, Vlissengen for Indonesian Navy, was commissioned on 2 July 2007. Based on the Dutch Sigma design, three other ships (F-366 through 368) were built in Netherlands and commissioned between 2007 and 2009. Two more are proposed.

Displacement	1692 tons, full load
Dimensions	90.7 m x 13 m x 3.6 m (Length, Beam, Draft)
Main Machinery	2 Diesels (21725 hp), 2 shafts
Speed, Range	28 Kts, 4000 NM at 18 Kts
Complement	80
Missiles	SSM: 4 MM 40 Exocet Block II, inertial cruise active radar homing to 40 NM at 0.9 Mach, warhead 165 kg. SAM: 2 quad Tetral launcher, MBDA Mistral, IR homing to 2.2 NM, warhead 3kg
Guns	1 76 mm/62, 120 rds/min to 8.7 NM, shell weight 6 kg, 2 20 mm MG
Torpedoes	6 324 mm tubes, MU-90, active/passive homing to 13.5 NM at 29/50 Kts
Countermeasures	2 Terma SKWS launcher, ESM/ECM
Helicopters	Platform only
Notes	Built for coastal security operations

Table 36. Sigma Class Corvette Characteristics.

Figure 15. KRI Diponegoro (F-365), from JFS.

Figure 16. KRI Sultan Hasanuddin (F-366), from JFS.

F. VISBY CLASS CORVETTE (FSGH)

HSWMS Visby (K-31), built at Karlskronavarvet for Swedish Navy, was commissioned on 12 July 2006. Four more ships (K-32 through 35) were commissioned between 2006 and 2008 in the Swedish Navy.

Displacement	620 tons, full load
Dimensions	73 m x 10.4 m x 2.4 m (Length, Beam, Draft)
Main Machinery	CODOG, 4 GT (21760 hp), 2 Diesels (3536 hp), 2 Waterjets, bow thruster
Speed	35 Kts, 15 Kts (diesels)
Complement	43
Missiles	8 RBS 15 Mk 3, inertial guidance active radar homing to 110 NM at 0.9 Mach, warhead 200 kg
Guns	1 57 mm/70 Mk 3, 220 rds/min to 9.3 NM, shell weight 2.4 kg, 2 12.7 mm MG
Torpedoes	4 400 mm tubes, Type-45, anti-submarine/surface, wire guided active homing to 10.8 NM at 25 Kts, warhead 45 kg
Countermeasures	Rheinmetal decoy launcher, ESM/ECM, MCMV
Helicopters	Platform only
Notes	SAM provision is TBC, but most likely South African Umkhonto 16-cell VLS, inertial guidance with mid-course guidance and IR homing to 6.5 NM at 2.4 Mach, Warhead 23 kg

Table 37. Visby Class Corvette Characteristics.

Figure 17. HSWMS Visby (K-31), from JFS.

Figure 18. HSWMS Helsingborg (K-32), from JFS.

G. SIKORSKY MH-60R SEAHAWK

MH-60R Seahawk is built for the U.S. Navy to replace the aging SH-60B/F fleet. It will serve as the future tactical helicopter operated from surface combatants. Entered in the frontline service in 2006, MH-60R is equipped with a full-spectrum of airborne sensor suits, equipments and weapons for principal naval warfare. Recent product improvements to the helicopter include the fourth weapons station, allowing a total of eight AGM-114 Hellfire missiles or four Mk-54 torpedoes. Besides the modern sensors and lethal weapons load, having an operational speed of 145 knots and a range of 450 NM, MH-60R Seahawk is one of the most effective tactical helicopters operated from ships.

Figure 19. MH-60R Seahawk, from JFS.

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APPENDIX B. OPPOSING FORCE ASSETS

A. KILO CLASS (PROJECT 877 EKM) SUBMARINE (SSK)

Three Kilo class submarines were built for Iranian Navy by the Admiralty Yard in St. Petersburg and commissioned in 1992, 1993 and 1996.

Displacement	3076 tons submerged
Dimensions	72.6 m x 9.9 m x 6.6 m (Length, Beam, Draft)
Main Machinery	2 Diesels (3650 hp), 1 electric motor (5500 hp), 1 shaft
Speed, Range	17 Kts dived, 6000 NM at 7 Kts snorting
Complement	53
Torpedoes	6 533 mm tubes, combination of TEST-71/96 wire guided active/passive homing to 8.1 NM at 40 Kts, warhead 220 kg and 53-65 passive wake homing to 10.3 NM at 45 Kts, warhead 350 kg. Total of 18 torpedoes. 24 mines in lieu of torpedoes
Notes	Chinese YJ-1 or Russian Novator Alfa SSMs and SA-N-10 SAMs may be fitted during the planned upgrade refit of the boats

Table 38. Kilo Class Submarine Characteristics.

Figure 20. Iranian Kilo Class Submarine-1, from JFS.

Figure 21. Iranian Kilo Class Submarine-2, from JFS.

B. YONO CLASS (IS 120) COASTAL SUBMARINE (SSC)

Based on the North Korean design, a total of five submarines are claimed to have been built in Iran and one more is under construction. These are likely to be involvement with North Korea. First noticed in 2004, little is known about these boats.

Displacement	123 tons submerged
Dimensions	29 m x 2.8 m x 2.5 m (Length, Beam, Draft)
Main Machinery	Diesel-electric
Complement	32
Torpedoes	2 533 mm tubes

Table 39. Kilo Class Submarine Characteristics.

Figure 22. Iranian Yono Class Submarine, from JFS.

C. KAMAN (COMBATTANTE II) CLASS FPB (PGFG)

Ten boats were built by CMN in Cherbourg, France for Iranian Navy and commissioned between 1977 and 1981. Three more of this class were built by Iran at Bandar Anzali on Caspian coast and commissioned in 2004, 2006 and 2008.

Displacement	275 tons full load
Dimensions	47 m x 7.1 m x 1.9 m (Length, Beam, Draft)
Main Machinery	4 Diesels (12280 hp), 4 shafts
Speed, Range	38 Kts, 2000 NM at 15 Kts
Complement	31
Missiles	2 or 4 C-802, active radar homing to 66 NM at 0.9 Mach, warhead 165 kg
Guns	1 76 mm/62, 85 rds/min to 8.7 NM, shell weight 6 kg, 1 40 mm/70, 300 rds/min to 6.6 NM. Some have 23 m or 20 mm gun in place of 40 mm 2 12.7 mm MG
Notes	SA-7 portable SAMs maybe embarked. Latter built boats are stationed in Caspian Sea

Table 40. Kaman Class FPB Characteristics.

Figure 23. Iranian Kaman Class FPB-1, from JFS.

Figure 24. Iranian Kaman Class FPB-2, from JFS.

D. THONDOR (HOUDONG) CLASS FPB (PGFG)

Ten boats were built for Iranian Navy at Zhanjiang Shipyard, China and commissioned in two batches in 1994 and 1996.

Displacement	205 tons full load
Dimensions	38.6 m x 6.8 m x 2.7 m (Length, Beam, Draft)
Main Machinery	3 Diesels (8025 hp), 3 shafts
Speed, Range	35 Kts, 800 NM at 30 Kts
Complement	28
Missiles	4 C-802, active radar homing to 66 NM at 0.9 Mach, warhead 165 kg
Guns	2 30 mm AK 230, 2 23 mm MG
Notes	A similar design to Chinese Huangfen (Osa 1)

Table 41. Thondor Class FPB Characteristics.

Figure 25. Iranian Thondor Class FPB, from JFS.

E. C-14 CLASS MISSILE BOAT (PTG)

Nine boats were built by China State Shipbuilding Corporation and delivered starting 2000. Five boats are likely to carry short range Chinese FL-10 SSMs; while the remaining four have the Multiple Rocket Launcher (MRL).

Displacement	17 tons
Dimensions	13.7 m x 4.8 m x 0.7 m (Length, Beam, Draft)
Main Machinery	2 Diesels (2300 hp), 2 shafts
Speed	50 Kts
Missiles	4 FL-10
Guns	1 20 mm, 1 12.7 mm MG
Notes	A catamaran-hull design

Table 42. C-14 Class Boat Characteristics.

Figure 26. Iranian C-14 Class Missile Boat, from JFS.

F. MK 13 CLASS MISSILE BOAT (PTG)

Ten boats were built by China and delivered in 2006.

Displacement	TBA
Length	14 m
Speed	TBA
Missiles	2 FL-10
Torpedoes	2 324 mm tubes
Notes	Armed with both SSMs and torpedoes

Table 43. Mk 13 Class Boat Characteristics.

Figure 27. Iranian Mk 13 Class Missile Boat, from JFS.

G. PEYKAAP II (IPS 16 MOD) CLASS MISSILE BOAT (PTG)

Based on North Korean design of Peykaap I, it is estimated that 25 boats have been built recently by Iran.

Displacement	14 tons
Dimensions	17 m x 3.8 m x 0.7 m (Length, Beam, Draft)
Main Machinery	2 Diesels (2400 hp), 2 shafts
Speed	52 Kts
Missiles	2 C-701 Kosar
Notes	A slightly larger missile version of stealthy design Peykaap I torpedo boat

Table 44. Peykaap II Class Boat Characteristics.

Figure 28. Iranian Peykaap II Class Missile Boat, from JFS.

H. TIR (IPS 18) CLASS TORPEDO BOAT (PTF)

Ten of this class were built in North Korea and delivered in 2002.

Displacement	28 tons
Dimensions	21.1 m x 5.8 m x 0.9 m (Length, Beam, Draft)
Main Machinery	3 Diesels (3600 hp)
Speed	52 Kts
Guns	1 12.7 mm MG
Torpedoes	2 533 mm tubes
Notes	Anti-surface ships role torpedoes are carried

Table 45. Tir Class Boat Characteristics.

Figure 29. Iranian Tir Class Torpedo Boat, from JFS.

I. PEYKAAP I (IPS 16) CLASS TORPEDO BOAT (PTF)

Fifteen of this class were built in North Korea and delivered in 2002.

Displacement	14 tons
Dimensions	16.3 m x 3.8 m x 0.7 m (Length, Beam, Draft)
Main Machinery	2 Diesels (2400 hp), 2 shafts
Speed	52 Kts
Guns	1 12.7 mm MG
Torpedoes	2 324 mm tubes
Notes	A stealthy design carrying ship-disabling torpedoes

Table 46. Peykaap I Class Boat Characteristics.

Figure 30. Iranian Peykaap I Class Torpedo Boat, from JFS.

J. GAHJAE CLASS SEMI-SUBMERSIBLE TORPEDO BOAT (PTF)

Three of these boats were built in North Korea as Taedong-C semi-submersible boats and delivered in 2002.

Displacement	7 tons
Dimensions	15 m x 3 m x 0.7 m (Length, Beam, Draft)
Speed	50 Kts
Torpedoes	2 324 mm tubes
Notes	The stealthy design appears to be based on Peykaap I design. The concept of operations is a high speed surface approach to a target before submerging to a depth of 3 m. to conduct the attack using a snorting mast

Table 47. Gahjae Class Semi-Submersible Boat Characteristics.

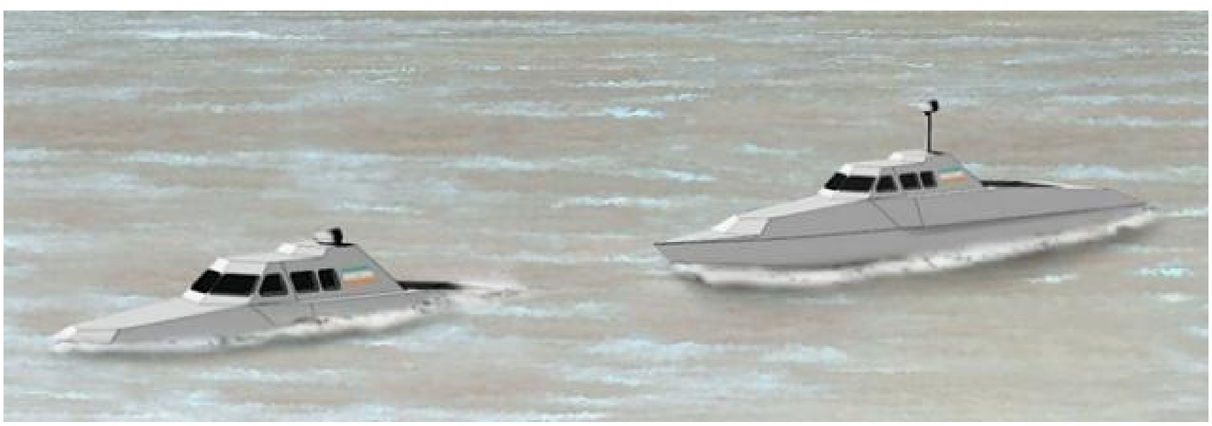

Figure 31. Iranian Gahjae Class Semi-Submersible Torpedo Boat, from JFS.

K. KAJAMI CLASS SEMI-SUBMERSIBLE TORPEDO BOAT (PTF)

Three of these boats were built in North Korea as Taedong-B high-speed infiltration crafts and delivered in 2002.

Displacement	30 tons
Length	21 m
Speed	50 Kts
Torpedoes	2 324 mm tubes
Notes	Little is known about the design. The concept of operations is a high speed surface approach to a target before submerging to a depth of 3 m. to conduct the attack using a snorting mast

Table 48. Kajami Class Semi-Submersible Boat Characteristics.

Figure 32. Iranian Kajami Class Semi-Submersible Torpedo Boat, from JFS.

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APPENDIX C. SALVO EQUATIONS ATTRIBUTE CALCULATIONS

A. FRIFOR ATTRIBUTE CALCULATION DETAILS

1. Defensive Power Calculations

Defensive power of all FRIFOR ships against submarines is two, due to lack of anti-torpedo defensive weapons. Only ASW defensive maneuvers are present for defensive power. Torpedo countermeasures of the surface ships are accounted for in the countermeasure effectiveness attributes. Against PTFs, all FRIFOR ships have a defensive power of three. Similar to the explanation for submarines, they lack defensive weapons. FRIFOR's ships early detection capability and better defensive maneuvers against PTFs give them a higher defensive power than against submarines. Defensive power of FRIFOR candidates against missile firing enemy ships, PGFGs and PTGs, are detailed in the following table.

FRIFOR	Defensive Weapon Values						
	SAM/PDMS	Value	Gun	Value	CIWS	Value	Total
Freedom	21 cell RAM	7	57 mm	2	-	0	9
Formid.	32 cell VLS	8	76 mm	1	-	0	9
MILGEM	21 cell RAM	7	76 mm	1	-	0	8
Stere.	8 tube IR	2.7	100 mm	1	4	4	7.7
Sigma	8 tube IR/RAM	2/7	76 mm	1	-	0	3/8
Visby	-/RAM	0/7	57 mm	2	-	0	2/9

Table 49. FRIFOR Anti-Missile Defensive Power Calculations.

All FRIFOR ships, except for Formidable and Visby, have IR missiles. Their defensive value is assumed 1/3 of the number of missiles available, except for Sigma, which is assumed at 1/4 due to her less effective system. For Formidable, the value is the number of FC Channels, which is four, and fairly becomes 1/4 of the number of missiles. 57 mm guns on Freedom and Visby are rapid firing and are assumed twice the value of the other guns. Each of regular guns and CIWS are assumed to effectively shoot down one incoming enemy missile. Steregushchiy has four CIWS; thus, with the combined CIWS and IR PDMS system, she is an effective defender. For the initial hardkill boost to Sigma

and Visby and with the addition of RAM, the value changes from three to eight for Sigma and from two to nine for Visby.

2. Staying Power Calculations

Staying power of all FRIFOR ships against submarine launched heavyweight torpedoes is one. Thus, it is assumed that one torpedo disables the surface ship from its role in the Salvo Exchange. Lightweight torpedoes and long-range SSMs (C-802s) are assumed to have the same disabling effect. This is because of their similar size of warheads and SSM’s possibly less lethal hit-point on its target. Short-range SSMs (all assumed to employ C-701s) are of a lesser lethal effect from PTGs; therefore, staying power against PTGs is higher. Staying power of FRIFOR candidates against missile and torpedo firing enemy surface ships, PGFGs, PTGs and PTFs, are detailed in Table 50.

FRIFOR	Length Coefficient	Tonnage Coefficient	Staying Power Values	
			Against C-802/ 324 mm torp.	Against C-701
Freedom	1.6	5	1.9	2.9
Formidable	1.6	5.2	1.9	2.9
MILGEM	1.4	3.2	1.5	2.3
Steregushchiy	1.4	3.5	1.6	2.5
Sigma	1.2	2.7	1.4	2.1
Visby	1	1	1	1.5

Table 50. FRIFOR Anti-Surface Ship Staying Power Calculations.

These calculations are based on Visby length and tonnage. The length and tonnage coefficients of Visby are assumed one. The rest of FRIFOR’s values are calculated by taking the ratio of them to Visby and dividing their lengths and tonnages with Visby’s. Visby’s staying power against C-802/lightweight torpedoes is assumed one and against C-701s is assumed 1.5. The following formula is used to calculate the FRIFOR’s staying power against C-802/lightweight torpedoes.

Staying Power = Leng. Coef. * 0.9 + Ton. Coef. * 0.1. (10)

Basically, length is 90% of the staying power; whereas, tonnage is 10%. Against C-701s, the former staying power value is simply multiplied by 1.5.

B. OPFOR ATTRIBUTE CALCULATION DETAILS

1. TG 480.04 Striking Power Calculations

TG 480.04 is composed of 10 PTGs, two Mk 13, two C-14 and six Peykaap II. Due to OPDEF, one C-14 and one Peykaap II are unavailable; therefore, eight PTGs are included in the calculations. Mk 13 normally carries two FL-10 and two lightweight torpedoes; C-14 carries four FL-10; and Peykaap carries two C-701s. For ease of modeling, however, it is assumed that they carry four, four, and two C-701s, respectively. Therefore, the striking power of TG 480.04 is calculated in the following formula.

Striking Power = (Number of 4 C-701 carriers * 4 + Number of 2 C-701 carriers * 2) / Total number of ships (11)

Eight boats, three of which carry four missiles and five boats that carry two missiles, yield a result of 2.8 for striking power.

2. TG 490.01-02 Striking Power Calculations

TG 490.01-02 is a combined TG of Thondor PGFGs and various classes of PTGs. TG 490.01 is composed of four Thondors, one is unavailable due to OPDEF and each has a striking power of four. TG 490.02 is composed of eight PTGs, three C-14 and five Peykaap II, and, due to OPDEF, one Peykaap II is unavailable; therefore, seven PTGs are included in the calculations. C-14 is assumed to have a striking power of four and Peykaap II has a striking power of two. Striking power of TG 490.02 was calculated in the previous section using the same formula. The result is 2.9. This striking power is combined with that of TG 490.01 in the following formula.

Striking Power of TG 490.01-02 = (Number of Thondors * 4 + Number of TG 490.02 * Striking power of TG 490.02) / Total number of ships (12)

There are three Thondors and seven PTGs; therefore, the result becomes 3.2.

3. TG 490.01-02 Defensive Power Calculations

Defensive power of Thondor is two, while the PTGs have a value of one. The formula below gives the result of 1.3

Defensive Power = (Number of Thondors * 2 + Number of TG 490.02 * 1) / Total number of ships (13)

4. TG 490.01-02 Staying Power Calculations

Against Hellfires, staying power of Thondor is 1.5 while the PTGs have a value of one. The formula below gives the result of 1.2.

Staying Power = (Number of Thondors * 1.5 + Number of TG 490.02 * 1) / Total number of ships (14)

Against the combination of FRIFOR Hellfires and SSMs, this value changes to approximately 1.1. The number is approximately the same for all ships attacking with a combination of missiles. A sample calculation is the following: Visby attacks with eight SSMs and four Hellfires, a total of 12 for striking power. The staying power of Thondor changes against Hellfires and SSMs. This combination, however, does not affect PTGs, which all have a value of one. So for Visby against TG 490.01-02, the staying power of OPFOR is the following formula.

Staying Power = ((Staying power against Hellfires * Number of Hellfires + Staying power against SSMs * Number of SSMs) / Number of FRIFOR missiles * Number of Thondors + Staying power against missiles * Number of PTGs) / Number of OPFOR ships. (15)

Thondor’s staying power against Hellfires is 1.5 and against SSMs it is one. The number of FRIFOR missiles is 12 and there are total of three Thondors. There are seven PTGs and, no matter what, the staying power is one. Thus, with a total number of ten OPFOR ships, the overall staying power of TG 490.01-02 becomes 1.1.

C. FRIFOR VS. TG 490.01-02 THONDOR-PTG ATTRIBUTE CALCULATION DETAILS

In this encounter, PGFGs and PTGs attack in a combined TG, while the FRIFOR ships respond with all offensive weapons combined. Freedom and Steregushchiy can only respond with helicopters and, therefore, with Hellfires. The remaining FRIFOR ships attack with both SSMs and

Hellfires. The fact that FRIFOR and OPFOR offensive weapons might be a mix of FRIFOR SSMs and Hellfires or OPFOR C-802 and C-701 SSMs, the staying power of OPFOR and FRIFOR might change as mentioned in the previous section. Depending on each FRIFOR ship, this is homogenized. Besides the staying power, WHP and Leakage Rate are also subject to change due to the weapons mix and these values are homogenized as well. Finally, for FRIFOR, since the OPFOR is a mixture of ships, the targeting effectiveness and defensive readiness are also homogenized.

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